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Full Name of Author – Nom complet de l'auteur
Shirley Faye Kushner

Date of Birth – Date de naissance November 17, 1952	Canadian Citizen – Citoyen canadien ☒ Yes / Oui ☐ No / Non
Country of Birth – Lieu de naissance Canada	Permanent Address – Résidence fixe 13508-106 Avenue Edmonton, Alberta Canada

THESIS – THÈSE

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University – Université University of Alberta	Name of Supervisor – Nom du directeur de thèse David Magee

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THE RELATIONSHIP BETWEEN SELECTED SPINAL CANAL MEASUREMENTS AND CLINICAL FINDINGS IN PATIENTS WITH LOW LUMBAR DISCECTOMY

by

© SHIRLEY KUSHNER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL THERAPY

EDMONTON, ALBERTA

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David Magee

Supervisor

John S. Kramer

Date Oct 3, 1985

DEDICATION

This thesis is dedicated to my grandmother
Fanny Hestrin,
my parents
Martha and David Kushner
and to
my sisters Susan, Leah and Frances

ABSTRACT

It has been stated that in patients with lumbar disc displacement, the spinal canal size and shape may be more significant than the size of the displaced disc.

The purpose of the study was to assess whether the shape or size of the spinal canal, as determined by computed tomography, was associated with selected clinical parameters preoperatively or postoperatively.

Twenty patients admitted for L4-L5 or L5-S1 discectomy to the Royal Alexandra Hospital in Edmonton, Alberta, were included in the study. Preoperatively and six weeks postoperatively, the patients were assessed for pain, straight leg raise, well leg raise, lumbar forward flexion, lateral flexion and extension. Computed tomography scans were obtained prior to surgery, and the spinal canal size was measured: sagittal and transverse diameters, and the cross-sectional area. The canals were also classified as oval, triangular, deltoid, or trefoil shape. All canals were evaluated at the vertebra above the involved disc.

Correlation coefficients were calculated to evaluate the association between canal measurements and clinical findings. One-way analysis of variance was used to determine whether there was a difference in the response of patients with different shaped canals. Multiple regression analyzed the proportion of variation in the clinical parameters explained by the preoperative values, canal sizes and canal shapes.

The sagittal canal diameter tended to be positively associated with movements in the anteroposterior plane, and negatively associated with movements in the transverse plane. The transverse canal diameter was positively associated with movements in the frontal plane, and tended to be negatively associated with movements in the sagittal plane.

The study showed minimal association of spinal canal measurements with pain. The straight leg raise and well leg raise tests related minimally to the canal sizes and shapes.

The largest association with improvement in spinal range of motion was not due to the canal size, but rather the canal shape. Patients with triangular shapes had the least improvement in spinal range of motion, as compared to those with deltoid and trefoil canals.

Patients with deltoid and trefoil shaped canals had the greatest improvement in spinal range of motion six weeks following low lumbar discectomy. Computed tomography scanning was useful for measurement of spinal canal shapes and sizes.

ACKNOWLEDGEMENTS

I am very grateful to Dr. Margaret Sin, for the unending guidance and assistance which she gave me throughout this project.

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This study could not have come to fruition without the help of many people at the Royal Alexandra Hospital to whom I would like to express my sincere thanks:

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LIST OF ABBREVIATIONS

AP	Anteroposterior
cm	Centimeter
CT	Computed Tomography
DELT	Deltoid Canal Shape
r	Correlation Coefficient
R	Multiple Correlation Coefficient
°	Degrees of Range of Motion
EXT	Extension
FLEX	Flexion
in	Inch
LFLEX	Left Flexion
MAS	Milliamperage Per Second
mm	Millimeter
$\bar{x}$	Mean
POSTOP	Postoperative
PPI	Present Pain Intensity
PREOP	Preoperative
ROM	Range of Motion
®	Registered Trademark
RFLEX	Right Flexion
n	Sample size
p	Significance
SD	Standard Deviation
SLR	Straight Leg Raise

TRIANG	Triangular
US	Ultrasound
WLR	Well Leg Raise

CHAPTER I

INTRODUCTION

Rationale

The assessment of lumbar disc displacement by radiographic and surgical procedures has influenced physicians and physiotherapists to be more concerned with the size of the disc lesion than with the shape and dimensions of the spinal canal (Porter 1978b). Grieve (1981) has stated that:

> A factor of critical importance is the size of the neural canal; a disc trespass of given extent will produce more serious clinical features in the patient with a less roomy canal.

Porter et al. (1978b) suggested that spinal canal space may be correlated with the patients' symptoms, signs, and subsequent results following surgery. The availability of computed tomography (CT) offers a method of determining a variety of spinal canal measurements as well as spinal canal shape.

The objective of the study was to determine the relationship of lumbar spinal canal morphometry, as measured by a computerized tomography scanner, to patients' clinical findings prior to and following discectomy at the L4-5 or L5-S1 level.

In miners and nurses with and without histories of lumbar disc displacement, Porter et al. (1978b) measured the sagittal oblique spinal canal diameters with ultrasound

(Figure 1). The space available in the canal was significantly related to the symptomatology of disc lesions. Fifty five percent of patients with disc symptoms had canal measurements below the fifth percentile of the asymtomatic subjects. As the spinal canals became narrower, more intervention was required. The patients who had disc lesions and settled at home tended to have larger spinal canal diameters than those patients who required inpatient traction. Patients requiring surgical treatment had the narrowest sagittal oblique diameters. The researchers concluded that wider canals minimized the chances of nerve root involvement, and the probability of failure to respond to treatment was related to the size of the canal rather than the size of the disc lesion. The measurement of all spinal canals prior to surgery was recommended. It is possible that the most suitable treatment for disc prolapse could be based on canal measurements (Park 1980, Winston 1984).

Different methods have been used in the past to measure the oblique sagittal (Figure 1), sagittal, transverse (Figure 2), lateral recess (Figure 3), and interfacet (Figure 4) spinal canal dimensions. The nerve root canals of the lumbar spine have also been measured (Bose and Balasubramaniam 1984). Diagnostic ultrasound, myelography, radiographs, venography and direct measurements at surgery, on bone specimens and cadavers have been used.

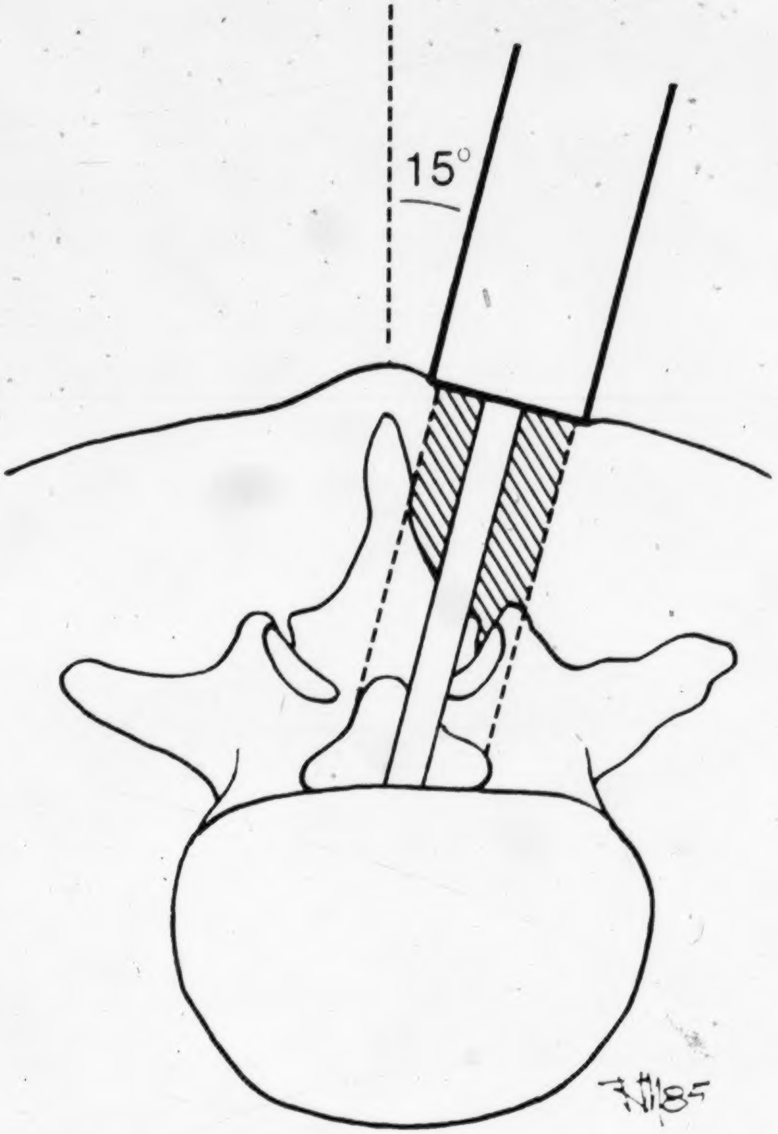
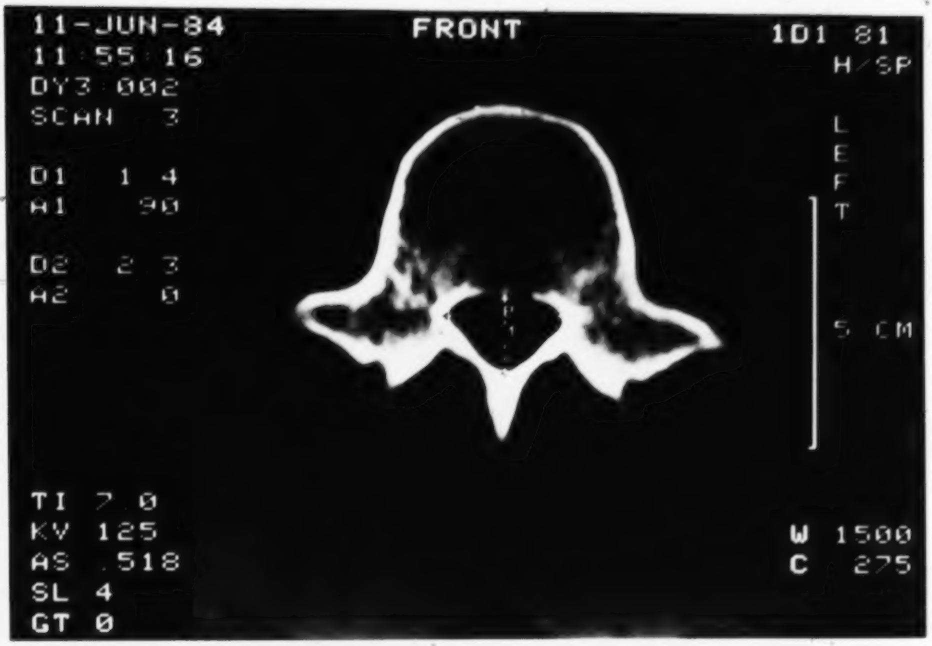


Figure 1. Sagittal Oblique Measurement With Ultrasound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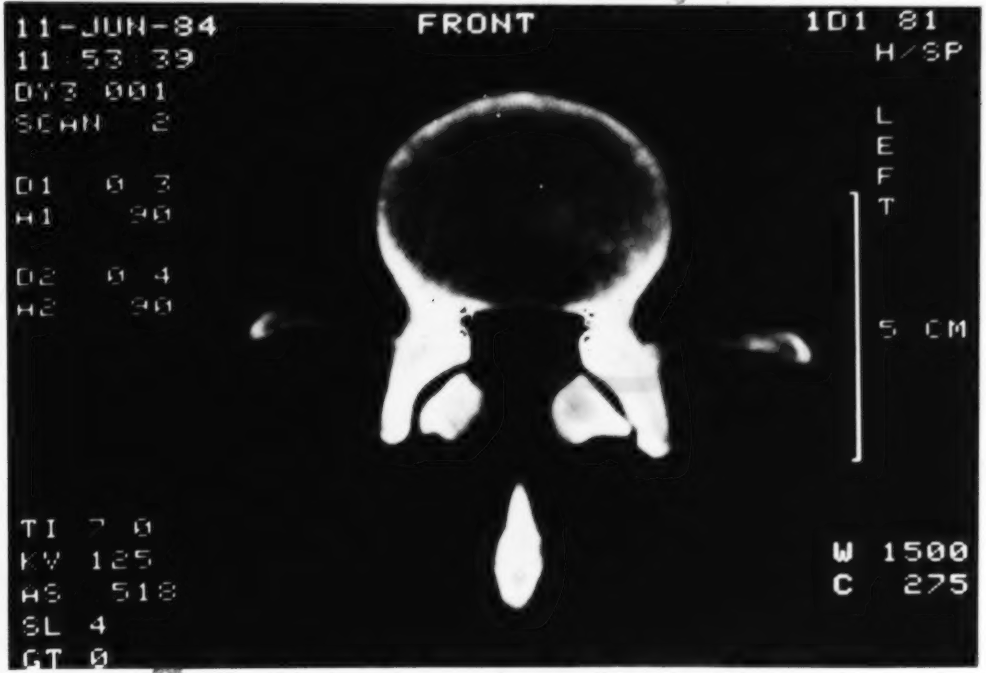
C 275

Figure 2. CT Scan With Sagittal Diameter Measurement (1), and Transverse Diameter Measurement (2)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KV 125
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Figure 3. CT Scan With Lateral Recess Measurement

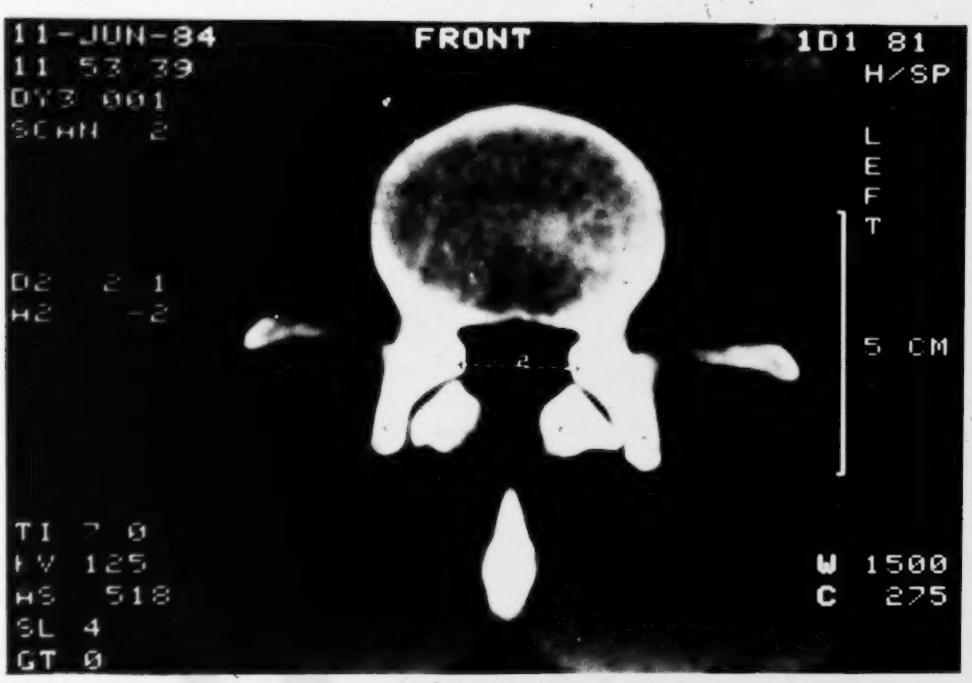
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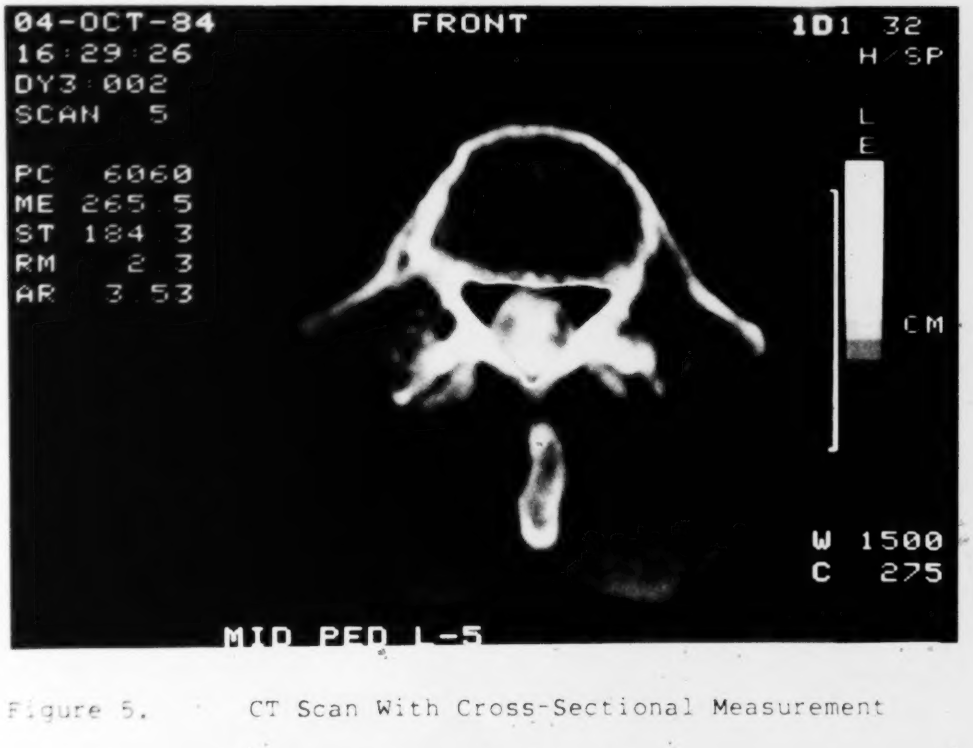
Figure 4. CT Scan With Interfacet Measurement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ME 265.5
ST 184.3
RM 2.3
AR 3.53
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CM
W 1500
C 275
MID PED L-5

Figure 5. CT Scan With Cross-Sectional Measurement

Recently, CT has been added to the list of canal measurement techniques, enabling the canal cross-sectional area (Figure 5) to be calculated (Postacchini et al. 1980, Ullrich et al. 1980). Computed tomography scanning appears to offer a more direct and accurate method of assessing the spine and disc displacement (Carrera et al. 1980, Meyer et al. 1979, Postacchini et al. 1980, Ullrich et al. 1980, Williams et al. 1980). CT has been postulated to be the future method of choice to establish a diagnosis of disc lesions, to facilitate a surgical plan, and to examine spinal canal shape and size (Burton 1983, Clark 1985, Eisenstein 1980, 1983, Finsterbush 1983, Isherwood 1980, Porter 1980, Otockdale and Finlay 1981, Veiga-Pires et al. 1981, Weir and DeLeo 1981, Williams et al. 1980).

Statement of the Problem

The size of the disc protrusion may be less responsible for the signs and symptoms of root compression than the size and shape of the spinal canal. Patients with a small canal may suffer earlier and more severely than their normally sized counterparts. The absence of space within a narrow canal might predispose the patient to the effects of neural compromise by minimal intrusions causing marked signs and symptoms (Choudhury and Taylor 1977, Ehni 1969, Epstein et al. 1962, Jones et al. 1968, Porter et al. 1978a; 1980, McCulloch 1977, Schlesinger and Tavernas 1953, Shapiro 1975, Verbeist 1955, Winston et al. 1984). The quality of results following discectomy may also be related to the canal size and shape.

Canal sizes and shapes have been measured previously. However, these measurements have rarely been related to the patients' clinical findings before or following treatment (Drinkall et al. 1984, Macdonald et al. 1984, Paine et al. 1976, Surin 1982, Verbeist 1975). As for surgical treatment, the CT measurements have never been correlated with clinical findings prior to or following surgery. An objective method for classifying canal shapes on the CT scanner has yet to be described.

Purposes of the Study

The purposes of the study were as follows:

1. To assess patients prior to and six weeks following surgery for straight leg raise (SLR), well leg raise (WLR), spinal range of motion (ROM), and subjective feelings of pain, in order to compare preoperative and postoperative values.
2. To determine whether a relationship existed between the sagittal diameter; transverse diameter (Figure 2); or cross-sectional area (Figure 5) measurements and the preoperative clinical findings.
3. To determine whether a relationship existed between the sagittal diameter; transverse diameter; or cross-sectional area measurements and the postoperative clinical findings.

4. To determine whether a difference existed between the different canal shape groups (Figure 6) in preoperative and postoperative clinical findings.
5. To determine the proportion of variation in the clinical parameters explained by the sagittal diameter, transverse diameter, cross-sectional area, or shape.
6. To determine whether a relationship existed between the sagittal, transverse, and cross-sectional spinal canal sizes.
7. To determine whether a relationship existed between spinal canal shapes and sizes.
8. To develop an objective standardized method of measuring transverse, sagittal and cross-sectional spinal canal sizes.
9. To develop an objective standardized method of measuring canal shape.
10. To utilize an objective reliable method of assessment of clinical findings in lumbar disc patients.

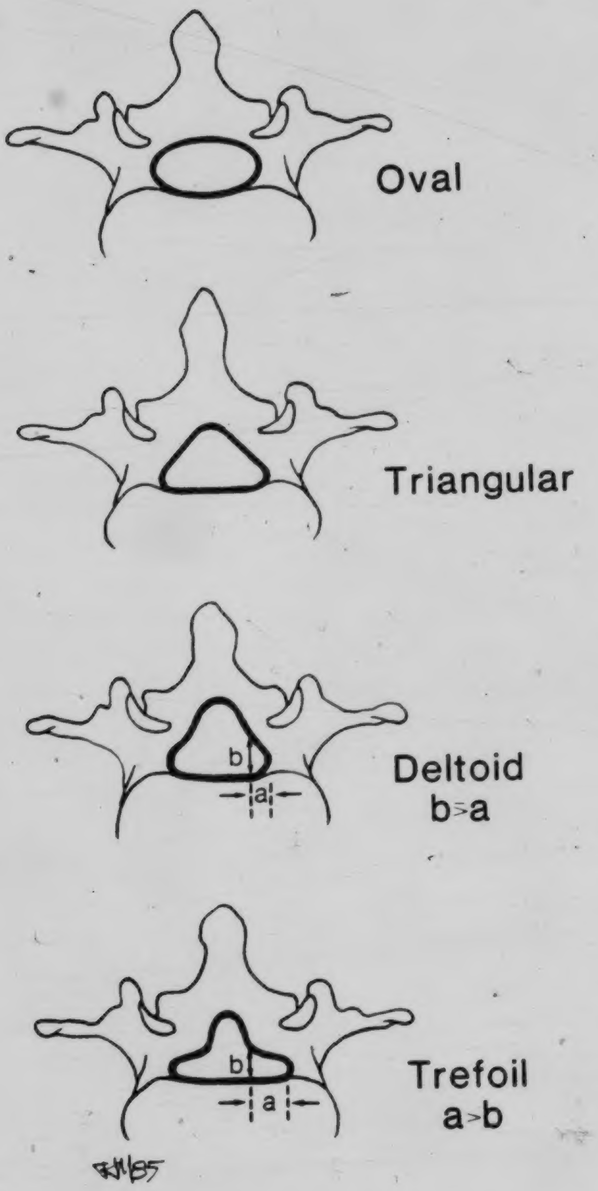
Oval
Triangular
b
a
Deltoid
b>a
b
a
Trefoil
a>b
GM/85

Figure 6. Lumbar Spinal Canal Shapes

Significance of the Study

There have been few studies relating vertebral canal diameter measurements to the patients' results following surgery. If canal size is related to the patients' results following treatment, this factor may have implications on treatment planning (Porter 1980).

Paine (1976) examined AP canal diameters by myelography in patients who underwent decompression for spinal stenosis. Decompressive relief was greatest in patients with the largest anteroposterior (AP) diameters (11 to 15 mm), while those with the smallest AP diameters (10 mm or less) had the most residual complaints. The method of canal measurement and specifics of myelography were not described.

Surin et al. (1982) examined patients undergoing decompressive laminectomy, and found that those with a smaller AP canal diameter (10 mm or less), as measured by myelography, tended to have fair and poor results following decompressive laminectomy while patients with larger canal diameters (11-14 mm) had good results. In both of the studies listed, a followup classification based on the patients' level of activity was used.

Ultrasound has been used to relate sagittal oblique diameters to development of low back pain, response to treatment, and time off work. Porter (1980) reported the development of disc symptoms to depend not only on the development of disc pathology, but also on the space available in the canal for displacement of the disc. The probability of failure to respond to surgical and conservative treatment was also related to canal size - the smaller the canal, the more intervention was required (Porter 1978b).

Macdonald et al. (1984) related oblique sagittal diameters in miners to low back pain. Men with the longest histories of low back pain, having taken the longest time off work, and having to leave the industry, had significantly narrower canals. Preemployment screening to identify the worker at risk of significant back pain was recommended.

Drinkall et al. (1984) studied patient outcome 12 months after presentation to the physician, and observed that patients with low back pain attending hospitals and general practices, had shallower canals than those without pain. A history of low back pain and the need to take time off work were related to smaller oblique spinal canal diameters. No association was found between canal size and recovery over 12 months. However, a standardized treatment was not described. Patient improvement was measured by completion of a questionnaire sent to the patients (treatment, time off work, present back pain, and physician attendances) rather than by patient examination.

Computed tomography, besides assessing for displaced discs enables standardized, objective and reproducible measurements of transverse and sagittal diameter, canal cross section and shape and has the benefit of being noninvasive.

Examination of the spinal canals is the first step to determine canal anthropometry. The need to know the normal shape and dimensions of the vertebral canal will become important as computerized tomography is more widely used in the assessment of the spinal canal in patients presenting with neural compression syndromes. The diagnosis of spinal stenosis using computerized tomography is impossible unless normal dimensions are established (Eisenstein 1983).

The natural progression from establishing norms in canal measurements is to relate these norms to patients presenting with clinical problems. As CT scans become increasingly common in the examination of the lumbar spine, the added information on canal size and shape could be related to the patients' signs and symptoms. If these relationships are found to be significant, they could have implications for treatment decisions. Patients with less reserve space within the spinal canal and increased nerve impingement might prove to be the best and most immediate surgical candidates, while those with the more spacious canals might be the best candidates for conservative physiotherapy treatment.

Delimitations

The investigation was delimited as follows:

1. The study was limited to twenty informed male and female patients ranging in age from 20 to 60 years.

2. Subjects had disc protrusions at the L4-L5 or L5-S1 levels as determined by the participating surgeons, Dr. Brian Greenhill and Dr. Ken Petruk of the Royal Alexandra Hospital, in Edmonton, Alberta, Canada.
3. Selection criteria for patients included combinations of the following: incapacitating episodes of sciatica, paravertebral muscle spasm, central back pain which persisted despite bedrest, an altered deep tendon reflex, dermatomal sensory changes, progressive muscle weakness, bladder or bowel dysfunction, flattening of the lumbar curve with an associated sciatic scoliosis of the spine, marked limitation of spinal movement, a positive straight leg raise test, or a positive well leg raise test (McNabb 1971, Spengler and Freeman 1979).
4. The definitive inclusion test was made at surgery by viewing a displaced disc: protruded, subligamentous prolapse, extruded or sequestrated (Figure 7). Only patients in which disc displacement was actually viewed at surgery were included in the study.
5. The surgical procedure was a discectomy or discectomy and partial laminectomy (laminotomy). Any additional procedure deemed necessary during the operation resulted in subject exclusion.
6. Exclusion criteria also included previous back surgery, spinal tumor, structural scoliosis, lumbar spine metabolic bone disease, lumbar spine infection,

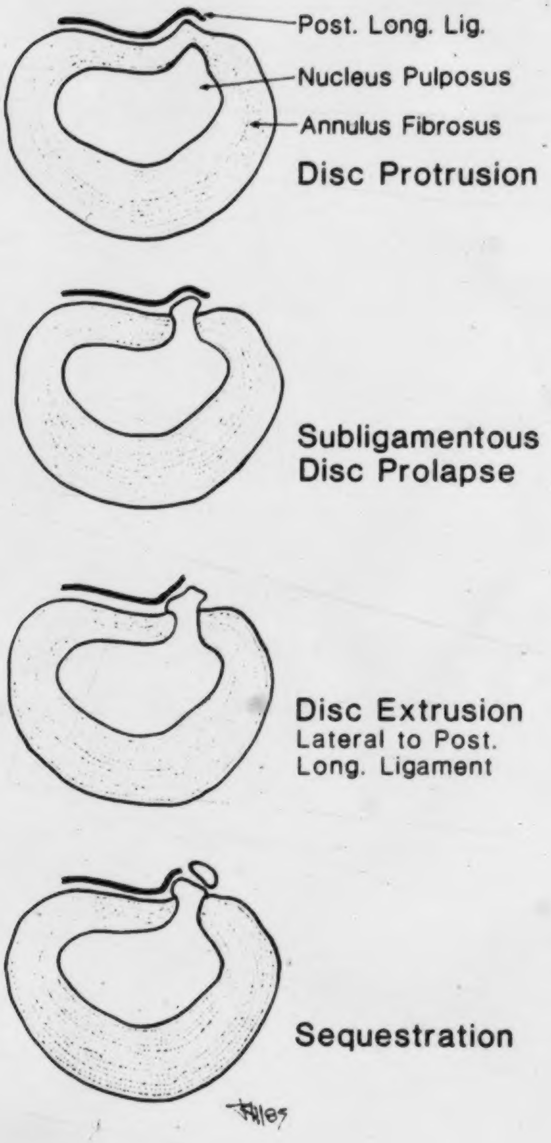
Post. Long. Lig.
Nucleus Pulposus
Annulus Fibrosus
Disc Protrusion
Subligamentous Disc Prolapse
Disc Extrusion
Lateral to Post. Long. Ligament
Sequestration

Figure 7. Disc Displacement Classification

spondylolysis, spondylolysthesis and peripheral vascular disease.

Limitations

The investigation was limited as follows:

1. Subject selection was made on a volunteer basis, and did not constitute a random sample of the lumbar patient disc population.
2. The sample of patients was small.
3. Patients were instructed not to return to work until the six week postoperative examination at the surgeon's office, and were given a home instruction sheet regarding activity (Appendix A). It was not possible to control for individual differences in activity levels.
4. Psychologic, occupational and other anatomic factors which may have affected the patient outcome have not been addressed.
5. Patients were reexamined at six weeks postsurgically, which may have been too early to represent the final outcome. This early assessment, however, enabled patient evaluation without the added variable of different types of work of the patients.

Definitions

A. Computed Tomography Scanning Definitions

1. Attenuation of X-rays: A process of energy absorption which produces the reduction of intensity of the x-ray

beam as it traverses matter by either absorption or deflection of photons from the beam. It is the percent of radiation remaining after the x-rays pass through an object (Johnston 1982).

2. Cathode Ray Tube: The television screen (image monitor) used to display CT image and to communicate (text monitor) with the computer (Figure 8).
3. Computed Tomography (CT): The process resulting in visualization of a thin cross-sectional image (a tomographic slice) of a body part. The image is created by a computer using a narrow x-ray beam that scans a thin slice of tissue from multiple angles taking multiple x-ray attenuation readings around a periphery of an object (Johnston 1982).
4. Computed Tomography Numbers: The numbers used to define a relative attenuation coefficient for each voxel of tissue in an image as compared with attenuation coefficient of the same volume of water. Tissues denser than water are given positive CT numbers and less dense tissues are given negative CT values. For example, air may be -1000 CT numbers, and very dense bone: +3071 CT numbers (Seimens 1982).
5. Electronic Pen: The pen used for measuring the canal dimensions on the image monitor by touching the resistor matrix (Figure 8) of the Somatom DR3®[1] (Siemens 1982).

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[1] Siemens Electric Limited, 9828-45 Avenue, Edmonton, Alberta, T6E 5C8

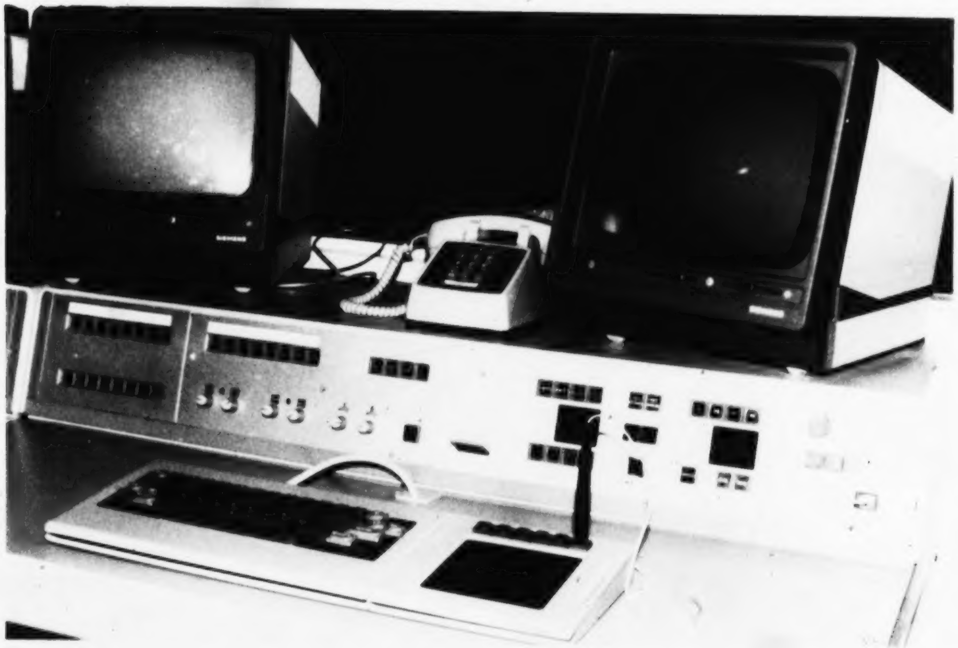

Figure 8. CT Control Console With Resistor Matrix and Electronic Pen

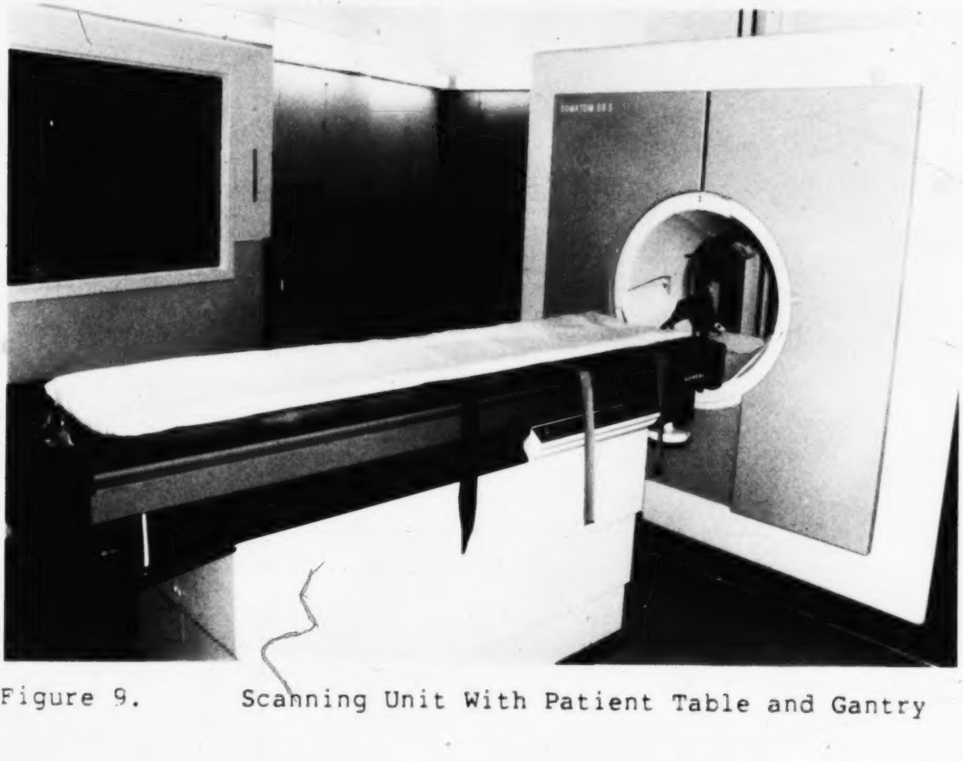

Figure 9. Scanning Unit With Patient Table and Gantry

6. Gantry: The framework that holds the x-ray tube and radiation detection system (Figure 9). The entire motion of the detector and the x-ray tube occurs within the housing of the gantry. In order to obtain images other than those perpendicular to the patient table (computed axial tomography), the gantry of the Somatom DR3® can be tilted to a maximum of 20 degrees in either direction of the vertical axis. The scan made is thus oblique to the patient axis (oblique tomography) and in line with the superior end plate (Johnston 1982, Siemens 1982).
7. Lateral Scout View (Topogram): A lateral view (Figure 10) enabling anatomic localization of the slice being taken. This view, has a number corresponding with each cross-sectional slice. It is valuable in examination of the spine because it shows the amount of angling of the gantry necessary in order to obtain a true axial image perpendicular to the longitudinal axis of the body.
8. Matrix: The two-dimensional array of numbers used to describe the number of pixels in the CT image display. Most CT systems use a 256 x 256, a 320 x 320, or a 512 x 512 matrix for displaying the images (Johnston 1982, Siemens 1982). The Somatom DR3® has the option of a 256 x 256 or a 512 x 512 matrix, however the 512 matrix was used for the study.
9. Pixel: The basic picture elements of the matrix and

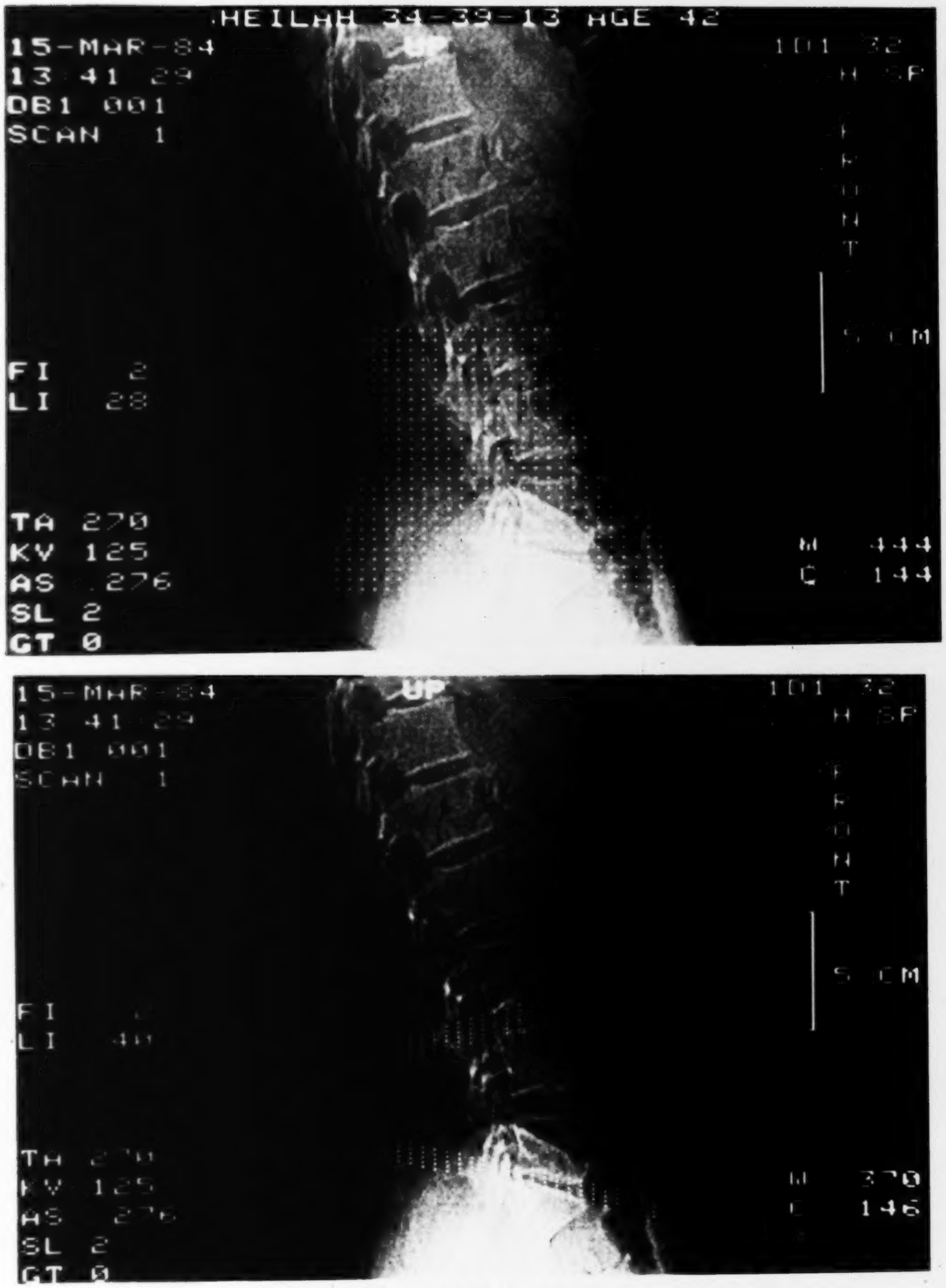
HEILAH 34-39-13 AGE 42
15-MAR-84
13 41 29
DB1 001
SCAN 1
UP
101 32
H SP
FRONT
5 CM
FI 2
LI 28
TA 270
KV 125
AS 276
SL 2
GT 0
W 444
C 144
15-MAR-84
13 41 29
DB1 001
SCAN 1
UP
101 32
H SP
FRONT
5 CM
FI
LI 40
TA 270
KV 125
AS 276
SL 2
GT 0
W 370
C 146

Figure 10. CT Scan of Lateral Scout View Not Angled (above) and Angled (below)

therefore the CT image. The data from the computer is displayed on the image monitor as many small squares, each representing a specific tiny cross section of the patient. Each square in the image matrix is called a pixel. Increasing the number of pixels within the same area gives a finer detail of the viewed image (Christenson et al. 1978, Johnston 1982, Ullrich et al. 1980).

10. Resistor Matrix: The square pad on the Somatom DR3® on which measurements of distance and area in the region of interest on the image monitor (Siemens 1982) are made with the electronic pen (Figure 8).
11. Slice: A cross-sectional thickness of a body part which is scanned for generating the CT image (Johnston 1982).
12. Window Centre (Level): A single CT number which represents the midpoint of the window width. By selecting the appropriate window settings, the operator can focus the computer's attention to any subgroup of CT numbers within the entire scale. For example, when viewing bone, a window width of 1500 CT numbers, and a centre of 275 CT numbers may be used, while for soft tissue, a window width of 500 CT numbers may be used with a centre of 25 CT numbers (Ullrich et al. 1980).
13. Window Width: The relative attenuation coefficient of tissue is measured by CT numbers. The window width sets the continuous range of units over which the grey step scale is displayed. On the image, pixels with numbers

greater than the upper window limit will appear white, while pixels with numbers less than the lower limit will appear black (Ullrich et al. 1980).

14. Voxel: The basic element that defines the volume of tissue that each pixel represents in the reconstructed image (Johnston 1982).

B. Surgical Definitions

1. Discectomy: The surgical removal of the protruded portion of the nucleus pulposus and the evacuation of the remaining nucleus pulposus from within the annulus fibrosus whereby no portion of the lamina is removed.
2. Partial Laminectomy (Laminotomy) and Discectomy: A discectomy and removal of only a portion of the lamina in order to allow access to the spinal canal.
3. Laminectomy and Discectomy: A discectomy and the full removal of the laminae in order to decompress the nerve root.

C. Assessment Definitions

1. Straight Leg Raise (SLR): Performance of the test is described under 'Materials and Methods'. A positive test is one which produces severe pain in the back, the sciatic distribution of the affected leg, or both (Finneson 1980). A negative test is one which causes no

discomfort other than a feeling of increasing tightness behind the knee in the hamstring region as the leg is passively raised.

2. Well Leg Raise (WLR): Performance of the test is described under 'Materials and Methods'. A positive test is one in which raising of the symptom-free leg gives rise to an exacerbation of pain in the affected side. The pain is as described under 'Straight Leg Raise' (Finneson 1980).

D. Disc Displacement Definitions (Figure 7)

1. Disc Protusion: The distortion of the annulus fibrosus allowing displacement of the nucleus pulposus. A localized or diffuse annular bulge is formed with the outermost annular fibres remaining intact.
2. Subligamentous Disc Prolapse: The disruption of the annular fibres allowing prolapse of the nucleus pulposus through the break in the annular fibres. The nucleus pulposus is constrained by the posterior longitudinal ligament.
3. Disc Extrusion: The nuclear material is extruded through the posterior fibres of the annulus fibrosus and lateral to the posterior longitudinal ligament but is still attached to the central nucleus.
4. Disc Sequestration: A free fragment of nuclear material may break through the annulus fibrosus and lose its

attachment to the central nucleus, lying free within the spinal canal with or without migration (MacNabb 1977).

E. Canal Shape Definitions (Figure 6)

1. Oval: The canal is elliptical shaped with no linearity on its sides and no definable lateral recesses.
2. Triangular: The sides of the canal are linear with no indentation and no definable lateral recesses.
3. Deltoid: The lateral recesses are deep and narrow (Baddeley 1976). Their AP dimensions are larger than their transverse dimensions. If one side of the canal is triangular and the other is deltoid, the canal is termed deltoid. If the AP and transverse areas of the lateral recesses are equal, the canal is termed deltoid.
4. Trefoil: The lateral recesses are wide and shallow (Baddeley 1976). The transverse dimensions of the lateral recesses are wider than the AP dimensions. If one side is trefoil and the other is deltoid, the canal is termed trefoil.

F. Statistical Definitions

1. Beta: A standardized regression coefficient in which the x and y are standardized to have unit variance. The

standard deviation of both x and y is equal to one, (x and y are expressed as z scores) and the constant is equal to zero and can be omitted (Kim and Kohout 1975).

2. Constant (A): The point at which the regression line crosses the y axis representing the predicted value of y when x=0 (Kim and Kohout 1975).
3. Correlation Squared (R^2): The proportion of variation explained by the variables in the regression equation which indicates the overall accuracy of the prediction equation.
4. Eta: A measurement of association appropriate for data when the dependent variable is measured on an interval scale and the independent variable on a nominal scale. It is assymetrical and does not assume a linear relationship between the variables (Norusis 1983). It is referred to as a nonlinear correlation coefficient.
5. Eta^2: The proportion of variability in the dependent variable that can be accounted for by knowing the independent variable (Norusis 1983).
6. Outlier: A point on a scatterplot different from the others which should be examined to see if an error has occurred in gathering, coding or entering of data, or if it is a deviant case vis-a-vis the relationship defined in the regression equation (Norusis 1983).
7. Pearson Product Moment Correlation Coefficient: A measure of association appropriate for data on an interval or ratio scale which measures the strength of

the linear relationship between two variables. The sign, magnitude and standardized slope can be interpreted from the correlation (Norusis 1983, Ferguson 1981).

8. Point Biserial Correlation: A measure of association between a continous variable and a dichotomous variable (Ferguson 1981). It is interpreted similarily to a Pearson correlation.
9. Slope (B): The constant in the regression line by which x is multiplied. The slope indicates the expected change in y with a change of one unit of x (Norusis 1983).
10. Standard Error of B (SE B): Standard deviation of the error of prediction in regression. It is the difference between the observed and predicted y values (Kim and Kohout 1975).
11. y': An estimated value of the dependent variable y (Kim and Kohout 1975).

Research Hypotheses

General Hypothesis

Patients with larger spinal canal sizes and shapes would have less severe signs and symptoms preoperatively and postoperatively and greater improvement in clinical parameters than would patients who have smaller spinal canal measures.

The specific research hypotheses were as follows:

1. Patients with smaller sagittal; transverse; and cross-sectional measurements would have lower preoperative values in SLR, WLR, spinal ROM, and higher values in pain than patients with larger canal measurements.
2. Patients with deltoid and trefoil shaped canals would have lower preoperative values in SLR, WLR, spinal ROM, and higher values in pain than patients with oval or triangular shaped canals.
3. Patients with smaller sagittal; transverse; and cross-sectional measurements would have lower postoperative values in SLR, WLR, spinal ROM, and higher values in pain than patients with larger canal measurements.
4. Patients with deltoid and trefoil shaped canals would have lower postoperative values in SLR, WLR, spinal ROM, and higher values in pain than patients with oval or triangular shaped canals.

5. Patients with smaller sagittal; transverse; and cross-sectional measurements would have less improvement postoperatively in SLR, WLR, spinal ROM, and pain than patients with larger canal measurements.
6. Patients with deltoid and trefoil shaped canals would have less improvement postoperatively in SLR, WLR, spinal ROM, and pain than those with oval or triangular shaped canals.

CHAPTER II

REVIEW OF THE LITERATURE

A. Epidemiology of Lumbar Disc Pathology

Low back pain is one of the most common and disabling conditions that affects people during their productive years (Kelsey and White 1980). Disorders of the lumbar spine have been reported to affect up to 80% of people in Western countries at some time in their lives (Anderson 1981, Kelsey and White 1980, Pope et al. 1980, White and Gordon 1982). In this decade, more than two billion people world wide will suffer from low back pain (Weisel et al. 1980). In England and Wales in 1970, 13.2 million work days were lost due to the painful back accounting for 3.6% of all sickness and injury incapacity and constituting a greater time loss than strikes (Benn and Wood 1975). Over 30% of compensation claims in the U.S.A. involved the lumbar spine (Mayer 1983), and diagnosis and treatment of back problems has been called the American medical system's greatest financial loss leader (Burton 1983).

Prolapsed discs affect an estimated 1% of Americans between the ages of 17 and 64. It is second in frequency for worker disability payment in people under 40 years (Kelsey and White 1980). The incidence of new cases per year is estimated at 0.1-0.5% of the population of 20 to 64 year olds (Kelsey and White 1980). In Alberta, in 1981, there were 9054 Workers' Compensation Board back ("spine and discs") claims with $6,292,773 in compensation paid. In 1982, there were 6048 claims with $8,327,470 paid (WCB 1983).

In Canada, disc displacement and its surgical treatment have profound implications on social and economic well being, as well as Canada's health care system. Statistics Canada (1982a) reported that in Canada, there were approximately 31,118 hospital admissions for "displacement of intervertebral disc" in 1978. In 1979, there were 30,304 cases of "intervertebral disc disorders" and in 1980 this number increased to 30,845 (1984a).

Thoracic disc protrusions occur in an estimated 2-3 per 1000 cases of disc protrusions or in 0.2%-0.3% of all disc protrusions (Love and Keifer 1950) while cervical protrusions occur with a frequency of about 14.29% of lumbar protrusions (Glista et al. 1977). These statistics indicate that approximately 85% of all disc protrusions occur in the lumbar spine so that one could estimate that of the Canadian statistics listed, the majority (85%) occurred in the lumbar spine. In 1978 in Canada, there were 11,312 surgical procedures for "excision of intervertebral cartilage" (not including the 2555 laminectomies and 4090 spinal fusions which were performed that year). The average length of hospital stay was 14.7 days (Statistics Canada 1982b). Statistics Canada (1984b) reported that by 1979, "excision or destruction of the intervertebral disc" was performed

10,607 times (with the average hospital stay at 13.9 days), and in 1980; the frequency was 10,638 (average hospital stay of 13.3 days).

In Alberta, from April 1, 1980, to March 31, 1981 (Hospitals and Medical Care 1983), the number of patients admitted to hospitals with primary diagnoses of lumbar intervertebral disc displacements with and without myelopathy, degeneration of the lumbar or lumbosacral intervertebral discs, lumbar disc disorders, neuralgia or neuritis of the sciatic nerve and lumbosacral neuritis or radiculitis came to approximately 3170. There were 853 admissions with a primary diagnosis of lumbago, low back pain or backache. The total length of hospital stay for the 4023 patients was 38,506 days. During that year, there were 1,322 operations for the primary diagnosis of "excision or destruction of the intervertebral disc" with the total days of hospital stay at 17,156.

The surgical treatment for a ruptured lumbar disc has become one of the most frequently performed surgical procedures in large American hospitals. An estimated 750 lumbar disc excisions per population of one million are done annually in the United States (Feild and McHenry 1982). This amounts to approximately 200,000 lumbar discectomies annually (Spengler and Freeman 1979). In Canada in 1978, the approximate rate of all disc excisions per 100,000 population was 97 (Statistics Canada 1982a). This figure is slightly higher than the figure for our American counterparts as it works out to 970 per million. However, the Canadian figure includes cervical and thoracic disc procedures. If one estimates that 85% of disc displacement occurs in the lumbar spine (Love and Keifer 1950, Glista et al. 1977), the Canadian figure is then reduced to approximately 825 disc excisions per million. The Canadian rate is decreasing annually from 97 per 100,000 procedures for "excision or destruction of the intervertebral disc" in 1978 to 90 per 100,000 in 1979 and 88 per 100,000 in 1980 (Statistics Canada 1984b). Elsewhere in the world, 125 disc excisions per million are performed (Field and McHenry 1982).

The levels of the lumbar spine which are most frequently affected by prolapsed discs are L4-L5 and L5-S1 (Gurdijan et al. 1961, Naylor 1974, Thomalske et al. 1979, Weir 1979). These levels account for about 95% of all lumbar disc herniations (Hakelius and Hindmarsh 1972). One to 5.9% of lumbar disc herniations occur above the fourth interspace (Aronson and Dunsmore 1963, Kelsey and White 1980, Kelsey and Ostfeld 1975, Lansche and Ford 1960, Raaf 1959).

There are several reasons for the lesions occuring more often at L4-L5 and L5-S1 than elsewhere in the lumbar spine. The lumbar lordosis puts these discs at an angle at which they are subject to more shearing stress than higher lumbar discs. Most of the movement in the spine takes place at L4 and L5 levels. The annulus fibrosus is not as dense and firm posteriorly (Finneson, 1980). Finally, the posterior longitudinal ligament is narrower at these levels, giving less support to the discs than at higher levels (Kelsey and Ostfeld 1975).

Some of the risk factors highly associated with lumbar disc prolapse are: the 30-39 year old age range, sedentary occupations, driving a motor vehicle, lifting especially when associated with twisting, living in the suburbs, and having full term pregnancies. Also associated are chronic cough, the male sex, insufficient physical exercise, baseball, golf and bowling; posture, spring and fall seasons, and a heavy frame (Kelsey 1975, 1978, Kelsey et al. 1984).

The age of patients with a diagnosis of "herniation of the intervertebral disc" is most often at 30-39 years (Kelsey and Ostfeld 1970, Kelsey 1975, Thomalske et al. 1979) and more specifically closer to 39 years. (Hakelius 1970). The age of most patients operated on for lumbar disc herniations is generally between 35-45 years (Andersson 1981, Naylor 1974, Hakelius 1970, Thomalske et al. 1979).

Statistics Canada reported (1984a) that in 1980, of 30,845 hospital admissions for displacement of the intervertebral disc, the highest frequency occurred in the 35-39 year olds constituting 13.87% (4279) of the displacements. This group was followed by the 40-44 year olds who had 13.21% (4075) of the displacements, then by the 45-49 year olds who had 12.24% (3775) of the displacements and by the 30-34 year olds with 11.98% (3696).

Alberta Hospitals and Medical Care (1983) reported that in 1980-81 of the 1322 operations for "excision or destruction of the intervertebral disc", the highest percentage occurred in the 30-39 year olds, with 28.4% (376 patients), specifically in the 30-35 year old group. The next most frequent age group was from 40-49 with 26.6% (351 patients), followed by ages 50-59 with 19.1% (252 patients).

Males are affected at a younger age than females (Kelsey and Ostfeld 1975): 30 to 34 years as compared to 40 to 44 years in the females. The male to female ratio has been described at about 2:1 (Kelsey and Ostfeld 1975; Sprangfort 1972; Thomalske et al. 1979). In Canada, however, in 1980, out of 30,845 admissions for "intervertebral disc disorders" 57.47% (17,728) were females, and 42.52% (13,117) were males (Statistics Canada 1984a).

Kurihara and Kataoka (1980) reported the incidence of lumbar disc herniation in children and adolescents to range from 0.8 to 3.8% in Caucasian patients and from 7.8 to 22.3% in Japanese patients. Given the same incidence of disc displacement in Japan, the Japanese have an increased tendency to develop sciatica. The Japanese develop herniated lumbar discs in the second and third decade whereas in Europeans and Americans it is more prevalent in the third and fourth decades. This, the authors felt, was due to the smaller Japanese skeleton size.

B. Spinal Canal Anatomy

The canal width varies in transverse and AP diameters at the various levels. In the cervical region, the canal is wide and spacious and triangular; in the midthoracic spine, it is smallest and circular, in the lumbar region; it is oval or round in the upper levels, and triangular or trefoil in the lower levels and in the sacral region; the canal is wide, flattened and triangular (Dommisse 1980, Helms and Vogler 1982, Lee et al. 1978, Postacchini et al. 1980, Porter 1980). The canal shape is variable at the L5 level, and most variable at S1 level (Choudhury and Taylor 1977, Dommisse 1975; 1980, Eisenstein 1980). There is a steady progressive increase in capacity from L1 to L5 in the tranverse plane which is consistent across race and sex. In the AP dimension, a slight narrowing occurs at the second, third, and fourth lumbar verterbrae (Amonoo-Kufi 1982, Eisenstein 1976; 1977; 1983, Postacchini et al. 1980; 1983).

Not only the size but the shape of the canal is significant (Porter 1980). The lumbar vertebrae provide a transition between the circular thoracic canal and the triangular sacral canal (Eisenstein 1980). Consequently the upper lumbar levels tend to be oval and triangular, and the lower levels: deltoid or trefoil (Baddeley 1976). There is an increasing tendency to trefoilness towards L5 (Porter, 1980).

C. Methods of Measurement of the Spinal Canal

Measurement of spinal canals are performed using one of six methods: 1. roentgenograms, 2. surgery (intraoperative measurements), 3. myelography, 4. diagnostic ultrasound, 5. measurement of bone specimens and cadavers and 6. computed tomography. The sagittal diameter, (Tables 1 and 2), transverse diameter (Tables 3 and 4) lateral recess width (Figure 3), sagittal oblique diameter (Figure 1), interfacet width (Figure 4), and the cross section (Figure 5) have been measured.

1. Roentgenograms

A roentgenogram is the most frequently carried out investigation for patients with low back pain. Hinck et al. (1966) established norms for interpedicular distances in 121 adult patients. Males were found to have marginally larger canals (Table 3).

Jones et al. (1968) developed the "canal to body ratio" in which the AP diameter and interpedicular distance were multiplied, and the product related to the similar measurement of the adjacent vertebral body. A ratio of 1:2 represented a large normal canal, and 1:4.5, a small normal canal.

This method was also used by Williams (1975). Her total range was between 1:2.5 and 1:8.0. At L4, the canal to body ratio ranged from 1:3 to 1:6, and at L5; from 1:3.2 to

1:6.5. Her patients had narrower canals than those of Jones et al., but only patients with severe enough back pain to warrant myelography were selected for the investigation. Eisenstein (1977) did not consider the spinal index of "canal to body ratio" to be relevant and preferred to concentrate on absolute dimensions at the midsagittal diameter of the canal.

Dommisse (1974) studied radiologically the interpedicular space of 50 normal individuals and in 1975, he measured the AP and transverse diameters in 25 skeletons (Tables 1 and 3).

Table 1

MEAN SAGITTAL CANAL DIAMETER MEASUREMENTS AND OBLIQUE SAGITTAL(‡) MEASUREMENTS(mm)

(Males=M, Females=F)

STUDY	YEAR	METHOD	SUBJECTS	L4	L5
Dommisse	1974	caliper	6 cadavers	15.1	15.4
Dommisse	1975	x-ray	25 skeletons	15.0	16.0
Eisenstein†	1977, 1983	x-ray, caliper	skeletons	443(1977)	485(1983)
			113 Caucasoid	16.0	18.0(M&F)
	330(1972), 372(1983)		Negroid	15.0	16.0(M)
			Negroid	15.5	16.0(F)
Porter‡	1978	US	200 normals	15.7	15.7
			78 patients	13.5	13.4
Postacchini	1980	CT	18 patients	16.1	17.1
Postacchini	1983	caliper	121 skeletons		
			63 Italian	15.1	16.5
			58 Indian	13.9	14.0
Winston	1984	x-ray	30 controls	19.6	18.0
			29 patients	18.0	16.5
Ullrich	1980	CT	60 normals	16.0	17.0
Drinkall‡	1984	US	193 patients	14.0	14.1
			132 controls	14.4	14.4
MacDonald‡	1984	US	152 patients	14.4	14.6
			52 controls	14.9	15.0
Legg‡	1984	US	50 normals	13.5	13.8

†Two studies (1977, 1983) using x-rays and calipers. The Caucasian male value was 17 mm in 1983.

Table 2

MINIMUM SAGITTAL CANAL DIAMETER MEASUREMENTS AND OBLIQUE SAGITTAL(‡) CANAL MEASUREMENTS (mm)

STUDY	YEAR	METHOD	MINIMUM
Ehni	1969	myelogram	15.0
Paine	1972	myelogram	15.0
Kirkaldy-Willis	1974	myelogram	14.0
Verbeist	1975	surgery	12.0
Sortland	1975	myelogram	15.0
Eisenstein	1977	radiograph	15.0
Porter‡	1978	US	14.0
Ullrich	1980	CT	11.5
Surin	1982	myelogram	14.0
Postacchini	1983	caliper	
		Italian(L4)	12.6
		Indian(L5)	11.5

Table 3

MEAN TRANSVERSE CANAL DIAMETER MEASUREMENTS(mm)

(Males=M, Females=F)

STUDY	YEAR	METHOD	SUBJECTS	L4	L5
Hinck	1966	x-ray	121 patients	27.6	30.7(M)
				26.4	29.0(F)
Dommisse	1974	caliper	6 cadavers	22.0	24.0
Dommisse	1974	x-ray	50 normals	26.0	29.3
Dommisse	1975	x-ray	25 skeletons	23.0	25.0
Eisenstein†	1977, 1983	x-ray, caliper	skeletons 443(1977), 485(1983)		
			113 Caucasoid	24.0	26.0(M)
				23.0	25.0(F)
			330(1972), 372(1983) Negroid	23.0	25.5(M)
				22.0	24.0(F)
Ullrich	1980	CT	60 normals	24.0	26.0
Amonoo	1982	x-ray	290 Negroid patients		
				26.0	28.7(M)
				25.4	28.4(F)
Postacchini	1983	caliper	121 skeletons		
			63 Italian	25.9	24.8
			58 Indian	21.1	22.8
Winston	1984	x-ray	30 controls	28.4	31.3
			29 patients	27.9	31.8

†Two studies with 433 and 485 skeletons using both x-rays and calipers. The values for both studies were identical.

Table 4

MINIMUM TRANSVERSE CANAL DIAMETER MEASUREMENTS(mm)

STUDY	YEAR	METHOD	MINIMUM
Paine	1972	myelogram	20
Verbeist	1975	surgery	17
Eisenstein	1977	radiograph	20
Ullrich	1980	CT	16

Table 5

MEAN AND MINIMAL CROSS-SECTIONAL CANAL MEASUREMENTS (cm^2)

STUDY	YEAR	METHOD	SUBJECTS	L4	L5	MINIMUM
Ullrich	1980	CT	60 normals	2.4	2.9	1.45

Dommisse (1975) also described a ratio of AP to transverse diameter. At L1, this ratio was 76 to 100, at L3, 68 to 100. At L5 the ratio was 64 to 100. The disproportion increased as one moved down the spine to the lowest levels where the highest number of discs prolapse (Kelsey and White 1980). At the S1 level, Dommisse (1975) found the AP diameter to be 13 mm and the tranverse diameter, 30 mm with the AP to transverse ratio at 43 to 100.

Eisenstein (1976) described a method of measurement of the posterior border of the canal in the lateral radiograph view to decrease the difficulty of measurement. In 1977 he measured a total of 2166 lumbar vertebrae on 433 adult Negroid and Caucasoid skeletons using radiographs and calipers at the midvertebrae (Tables 1 and 3). The Negroid canals were marginally narrower.

Amonoo-Kuofi (1982) studied the AP radiographs of 290 Negro lumbar spine patients and found the male canals to be consistently wider than the female canals, however the difference did not exceed 1 mm (Table 3). They also studied the canal/body ratio. The width of the canal maintained a constant relationship with the width of the body at all lumbar levels. They concluded that the width of the canal varied with different races.

Winston et al. (1984) examined the sagittal and interpedicular vertebral canal diameters from roentgenograms of 29 patients who had undergone lumbar laminectomy, and compared them with 30 controls. The vertebral canals were measured at the midpoint of the vertebral bodies. The sagittal canals were significantly smaller in the operated group. The interpedicular measurement had no significant difference between the groups (Tables 1 and 3).

Radiographs do not indicate the cross section or shape of the canal, nor do they necessarily show narrow lateral recesses, or soft tissue thickening (Ciric et al 1980, Jones et al 1968, Porter 1980, Shapiro 1975). Although the midsagittal diameter is thought to be more significant clinically, it is difficult to measure from a lateral radiograph because of superimposed shadows confusing the posterior canal boundary (Porter 1980, Postacchini et al. 1980, Williams 1975). Eisenstein (1983) reported that the need to establish the posterior limit by awkward extropolation technique would rapidly disappear with the advance of computerized axial tomography.

2. Surgery

Verbeist (1955, 1975, 1977) measured the size of the canal during surgery with a stensiometer. He stated that the surgeon who does not take into account the narrowness of the canal, may be astonished at the fact that the presence of such a small disc protrusion has been the cause of a complete block during myelography. A midsagittal diameter of 10 mm or less was defined as "pure absolute stenosis" which could produce cauda equina compression without additional compressive agents, and 10-12 mm was "relative stenosis", which was pathologic. Minimal midsagittal and transverse diameters were established (Table 2).

Choudhury and Taylor (1977) also measured the lumbar AP distances during surgery in 37 patients with lumbar stenosis. Their mean sagittal value was 21 mm, however the investigators did not give values that were specific as to level. The average the interfacet joint distance ranged from 1 to 3 cm in patients who had lateral recess stenosis.

Measuring during surgery has its drawbacks in that it is invasive, cannot give information prior to surgery, and cannot be remeasured as could, for example, a radiograph.

3. Myelography

Minimal acceptable AP diameters as evaluated by myelography are listed in Table 2, and the minimal acceptable transverse diameters as measured using this technique are listed in Table 4. Some of the reported measurements (Paine and Huang 1972, Sortland 1977) however, have been criticized for not using a correction factor for radiographic enlargement. According to Asztély et al. (1983), Sortland's (1977) minimal acceptable AP diameter of 15 mm at disc level should have been reduced to 10.5 mm after this correction. Sortland concluded that those with AP diameters less than 8-10 mm (corrected value: 5.5- 7.0 mm) had severe clinical complaints warranting surgery. Surin (1982) considered marked stenosis to be present if the AP diameter on the myelogram was less than 10 mm at disc level and moderate stenosis if the diameter was 10 to 14 mm (Table

2).

Myelography has been criticized for failing to reveal laterally placed stenotic lesions. A myelogram may show adequate AP and transverse diameters in a patient with lateral recess stenosis and a significantly reduced cross-sectional area (Ciric et al. 1980, Jacobson 1976, Kirkaldy-Willis et al. 1974, McAfee et al. 1981, McIvor et al. 1976, Porter 1978b, Postacchini et al. 1980, Shapiro 1975, Sortland 1977, Winston et al. 1984).

Choudhury and Taylor (1977) described patients with lateral stenosis causing nerve root compression yet with preservation of the normal limits of the sagittal diameter of the lumbar canal. Plain radiographs were not helpful and myelography was either negative or showed only minimal changes because of the normal AP diameter of the canal, lack of filling of the lateral recesses, and because the stenotic lateral canal was away from the theca.

Myelography is an invasive technique which may cause headache, nausea, vomitting, dizziness, scintillations and increased low back pain following the procedure (Sortland 1977). There is also a risk of arachnoiditis, seizures, radiculitis, venous intravasation with pulmonary embolism, and anaphylaxis (McAfee et al. 1981, Herkowitz et al. 1982).

Initial studies using advanced CT to evaluate intervertebral disc displacement have reported results as accurate or more accurate than myelography (Chafetz and Genant 1983, Kornberg et al. 1984). Armstrong(1984) compared

CT scanning and myelography in 23 patients with lumbar disc disease and physical findings of nerve root impingement. All patients had CT scans and metrizamide myelography. The "final arbitrator" was surgery. The scans were found to be useful in 96% of the studies compared to 71% for the myelograms. The researchers concluded that the "non-invasive, cost-effective" CT study can be more useful than a myelogram in evaluation of lumbar disc disease.

4. Diagnostic Ultrasound

An ultrasonic method of measuring the oblique sagittal canal diameter (Figure 1) was developed by Porter et al. (1978b, 1978a) in order to assess the significance of the canal diameter in the presence of disc symptoms. In their study of miners and nurses of whom 73 had lumbar disc symptoms and 200 were controls, they found the following: The mean diameter of asymptomatic patients at L4 and L5 was 1.57 cm while in the symptomatic group, the mean was 1.35 cm at L4 and 1.34 cm at L5 (Table 1). Of this group, the 28 discs (38%) which settled at home had a mean diameter of 1.38 cm (L4) and 1.37 cm (L5). In the 24 patients (33%) comprising the inpatient traction group, the mean diameter was 1.32 cm (L4) and 1.35 cm (L5), and in the 21 patient(29%) surgical group, the mean diameter was 1.33 cm (L4) and 1.27 cm (L5). They concluded that patients with measurements of less than 1.4 cm at L4 and L5 were at risk and that the space available in the spinal canal was highly significant in the symptomatology of disc lesions.

Sixty eight percent of patients with disabling disc symptoms had canal measurements below the tenth percentile of asymptomatic subjects. Mean female values were slightly greater than mean male values. The researchers concluded that many patients with wider canals escaped root involvement in the presence of disc prolapse. They suggested that canal measurement could be important in vocational cousellling and economically relevent in reducing morbidity. Young subjects at risk could be identified easily and advised against hazardous occupations and recreations.

Drinkall et al. (1984) and MacDonald et al. (1984) have confirmed Porter's studies that patients with shallower canals had more back pain than the controls, had to take more time off work, and were more likely to change occupations due to low back pain. Legg and Gibbs (1984) found measurements of approximately 0.2 cm less than those previously reported using ultrasound in 50 normal males. Oblique sagittal canal diameters are listed in Tables 1 and 2.

Using diagnostic ultrasound, only the sagittal oblique diameter of the canal can be assessed. This method of measurement does not give accurate information regarding canal shape or cross section, or sagittal and transverse diameters, lateral recesses or interfacet measurements of the canal. Despite ultrasound advocates' claims of high repeatability values (Hibbert et al. 1981), replication of this technique has been reported unreliable, inaccurate, and highly dependent on the skill of the operator (Aszteléy et al. 1983, Finlay et al. 1981, Kadziolka et al. 1981, Legg and Gibbs 1984, Macdonald et al. 1980, Stockdale and Finlay 1980). The technique has also been criticized for not measuring a "unique dimension" of the canal (Davies 1982). Rather, it gives a measurement on an angle of about 15° from the sagittal (Figure 1), whose value is not exact or "unique" - as would be an AP or transverse measurement - so is more difficult to standardize. Also, ultrasound is an extra test which would need to be obtained specifically for canal measurement. Diagnostic ultrasound does not appear to be of benefit over CT scanning for canal measurement (Postacchini et al. 1980). It is claimed only to "reflect" the narrowing of a trefoil canal and "predict" the canal shape (Porter 1982).

5. Bony Specimens and Cadavers

Straight measurement of canals on specimens and cadavers has also been reported in the literature.

Dommisse (1974) measured six cadaver canals with Vernier calipers. The mean values are reported in Tables 1 and 3.

Eisenstein (1983) measured the spinal canals of 485 male and female Caucasian, Zulu and Sotho skeletons. He felt that the diagnosis of spinal stenosis on computerized tomography was impossible unless normal dimensions were established. He measured both the transverse and AP diameters using a Vernier caliper as described by Jones et al. (1968). The large contribution of this study was that exact location of the measurements was standardized. The AP measurement was taken from the slightly anterior bulge on the posterior wall of the canal along a line perpendicular to the posterior vertebral body wall (which is the most recessed part of the body where a foramen for blood vessels is often found). The transverse diameter was measured at the canal's greatest interpedicular diameter which was at the same level as the midsagittal diameter. The Negro skeletons (Sotho and Zulu) had marginally smaller diameters than the Caucasian group.

The mean values are reported in Tables 1 and 3. They do not differ substantially from Eisenstein's earlier reported radiographic and caliper measurements (1977), except that the Caucasian male AP diameter at L5 was 17 rather than 18 mm. He cautioned that the two measurements did not exhibit the true shape of the lumbar canal and that one of the virtues of computerized tomography was that it would display the canal shape.

Postacchini et al. (1983) assessed normal variations in the diameters of the canals of 121 adult Indian and Italian skeletons using Vernier calipers. They measured cephalad and caudal midsagittal diameters and canal interpedicular diameters at a standardized location. They also measured the vertebral body height; vertebral body midsagittal and transverse diameters, and the thickness of the laminae and the width of the lateral recesses in the midsagittal plane. The measurement was done in order to establish normal guidelines which, they stated, have become of primary clinical importance with the advent of CT. The mean dimensions of the canal, lateral recesses and vertebral body were found to be significantly greater in Italian than Indian skeletons. The caudal and cephalad measurements were very similar and have been averaged and listed in Tables 1 and 3. The lowest normal limits of the midsagittal diameters of the spinal canal are listed in Table 2. Midsagittal diameters of less than 11 mm were almost always found in the fourth and fifth lumbar vertebrae. The current belief (reported by Verbeist 1975) that a midsagittal diameter of the canal of less than 12 mm is pathologic was questioned. They concluded that dimensions of the canal and body vary between different ethnic groups and that there were no mean values or lower limits of normal that were valid for all populations, even of the same race. They cautioned that the diagnosis of developmental stenosis could not be based rigidly on morphometric studies alone.

Direct measurement of the canal on skeletal specimens and cadavers is the simplest and most straightforward method of measurement, and can give very valuable and relevent information, but of course has inherent drawbacks clinically.

6. Computed Tomography

CT scanning for spinal canal measurement can with ease, give information on canal diameters, cross section and shape. It provides detailed presurgical information on encroachment in lateral recess stenosis, (Ciric et al. 1980, Postachinni et al. 1980) and demonstrates not only disc displacement (Meyer 1979), but also facet joint disease and spinal stenosis which may simulate or complicate herniation (Isherwood 1980, McAffee 1981, Porter 1980, Weir and DeLeo 1981, Williams et al. 1980).

Computed tomography was first introduced in 1973 to investigate intracranial diseases (Isherwood 1980, Hirofugi 1983). Since 1976, it has been used to obtain images of the vertebrae and the spinal canal (Gould 1982, Hirofugi 1983). It rapidly caught on over conventional radiographs due to its contrast sensitivity, elimination of superimposed structures as seen on conventional radiography and because it depicts subtle differences of the cross section of the spine (Isherwood 1980, Gould 1982). In assessment of disc herniation, CT permits evaluation of the relation between the disc bulge and the dura or root, thereby confirming diagnosis and allowing formulation of a precise surgical plan (Hirofugi 1983). It provides an axial projection of topographical anatomy against a detailed background of paravertebral muscles, vascular structures, and body cavity organs (Isherwood 1980).

Computed tomography has gone through rapid development since it was first introduced in 1973. Scan time and reconstruction time has been markedly reduced, the image matrix has increased, pixel size has decreased, number of detectors has increased from one to about 600 for each slice, and improved spatial resolution and changes are still evolving (Gould 1982, Genant 1982). The indications for CT in patients with low back and leg pain are expanding as resolution of the scanners improve (Meyer et al. 1979).

Meyer et al. (1979) found CT reliable in diagnosis of herniated lumbar discs in 25 patients. They found CT advantageous over myelograms, due to the decreased risks, the presurgical advantage of seeing an accurate cross section of the offending disc and displaced nerve root; the facet joints and the cross sectional area of the spinal canal. In complicated cases, they recommended myelography as a useful adjunct to CT.

Williams et al. (1980) studied the effectiveness of CT scanning without intrathecal contrast in patients with suspected lumbar disc herniation. Twenty five out of 35 cases were positive on the CT scan for disc displacement, and out of 16 cases treated surgically, all scans had close correlations with operative findings. No false positives were encountered. They concluded that CT accurately demonstrates disc herniations.

Ullrich et al. (1980) using CT, measured the canals of 60 patients admitted to the hospital for abdominal investigations. The canal cross-sectional area, AP diameter, and interpediculate distance were measured and normal values were established. The vertebrae were divided into four zones for measurement: upper, middle, lower vertebral body, and disc space. The canal area was calculated by using the irregular region of interest function to outline the canal, and the histogram function to count the pixels within the circumscribed area. They then multiplied the area per pixel by number of pixels. Their mean canal diameters taken at the midvertebral body and minimum acceptable measurements are listed in Tables 1 through 6. Measurements at the lower vertebral body tended to be slightly larger. The investigators found tilting the gantry to be unrewarding because the correct angle was elusive and could be difficult to localize anatomically. They preferred to reconstruct CT images in the sagittal plane. They did not, however, use a localizing device which would have simplified the anatomic identification of CT images. Also, they used a large pixel size and a small matrix (256 x256) which likely distorted measurement. The images were 13 mm thick and scan time was 18 seconds, and they did not correct for the lumbar lordosis. Their cross-sectional measurements may not have been as accurate as those possible with the improved parameters presently available with third and fourth generation scanners.

Postacchini et al. (1980) used CT in 18 patients with lumbar stenosis. Scans were performed through the pedicles, disc space, and caudal half of the vertebrae. The sagittal diameters have been averaged and are reported in Table 1. They failed to record transverse diameters for each level and instead reported a mean lumbar diameter of 23 mm. The investigators also reported the spinal index of Jones et al. (1968); 1:1.2 in the large canals, and 1:4.7 in the small canals.

The need to know the normal shape and dimensions of the vertebral canal would become more pressing as computerized tomography is more widely used in the assessment of the spinal canal in patients presenting with neural compression syndromes (Eisenstein 1983). Computed tomography is ideal for the assessment of spinal canal size and configuration (Ullrich et al. 1980).

D. Patient Assessment

1. Straight Leg Raise

The straight leg raise test has many variations and adjuncts. These variations include the Lasegue test (Scham and Taylor 1971), sitting sciatic tension test (Deyerle and May 1956), posterior tibial nerve sign (Cram 1953) or bowstring sign (MacNabb 1977), reverse SLR (MacNabb 1977), bilateral SLR (O'Connell 1953), the WLR test (Woodhall and Hayes 1950), and qualifying tests such as medial hip rotation, dorsiflexion, and flexion of the cervical spine

(Brody 1969, Troup 1981, Rothman et al. 1982)

The SLR has been described as the most informative clinical sign in the diagnosis of a protruded disc (Charnley 1951). As the leg is raised, tension develops within the nerve root (O'Connell 1943, Murphy 1977). This test exerts traction on the sciatic nerve, lumbo-sacral nerve roots, and the dura (Goddard and Reid 1965).

Cadaver dissection has shown that initially, when the heel is elevated one to three inches, the slack is taken up in the sciatic nerve as movement occurs at its exit from the pelvis (Murphy 1977, Charnley 1951). At 20-40° from the horizontal, this stretching reaches the intervertebral foramina (Goddard and Reid 1965, Murphy 1977). The slack in the sciatic nerve is taken up at this point. Only once this slack is taken up is traction exerted on the nerve roots at the intervertebral foramina and proximally.

Normally, the root then begins to move and, distal migration of the nerve roots through the foramina occurs. The migration for the fifth lumbar and first and second sacral nerves varies from 2-8 mm and is maximal at 60 to 90° of hip flexion with little additional movement beyond 70°of straight leg raising (Charnley 1951, Fahrni 1966, Falconer et al. 1948, Goddard and Reid 1965, Woodhall and Hayes 1950). The fourth lumbar roots move downwards to a lesser extent and the remaining ones do not move at all (Falconer et al. 1948). Goddard and Reid (1965) found the greatest amount of movement to occur distally in the sciatic nerve and to lessen towards the foramina. This restriction of proximal movement was attributed to the light tethering of the sciatic nerve and its roots to adjoining fascia and periosteum at its lumbopelvic course. The tethering effect on innumerable filmy fibrous adhesions in the region of the foramina makes the nerve root a fixed point from which downward stretch occurs (Goddard and Reid 1965, Murphy 1977, O'Connell 1943).

If another structure such as a protuded disc is impinging upon the nerve root during the test, some of the slack in the neuromeningeal pathway is taken up prior to the test being initiated. Tension in the nerve root is increased prior to the subsequent test (Urban 1981). During the SLR test, the affected nerve root tightens over the summit of the protrusion and the distance which the hip can be flexed before the tension develops in the nerve root is reduced. The prolapse restricts free movement of the nerve roots through their foramina (Falconer et al. 1948).

Of 2157 patients with surgically verified disc protrusions, Sprangfort (1972) found the test to be positive in 96.8% of the cases.

2. Well Leg Raise

This test is also known as the cross-over test, crossed-straight-leg-raising-test, crossed sciatic test, crossed Lasegue test, the contralateral leg phenomenon, and the well-leg-raising test of Fajersztajn (Brody et al. 1969, Fahrni 1966, Hakelius and Hindmarsh 1972, Hudgins 1977, Sjoqvist 1947, Woodhall and Hayes 1950).

The well leg raise test was first described by Fajersztajn in 1901 (Woodhall and Hayes 1950). The test involves raising the symptom free leg in the same manner as the straight leg raise test, which aggrevates the pain in the affected extremity. A positive WLR test might be a very strong confirmation of nerve root involvement, and has been reported as the most reliable and definate clinical sign, or pathognomonic, of disc herniation (Hudgins 1977, Hakelius and Hindmarsh 1972). Some authors feel that this test is more significant than the ipsilateral variety (Urban 1981). As the sciatic nerve of the unaffected leg moves caudally, lateral tension is transmitted through the dural sac to the affected roots on the contralateral side (Scham and Taylor 1971, Brieg and Troop 1979, Hakelius and Hindmarsh 1972, Sjoqvist 1947, Rothman et al. 1982). A greater degree of elevation is necessary in the well leg than in the affected one in order to produce the same amount of pain (Scham and Taylor 1971, O'Connell 1943).

Not only is the test very suggestive of a displaced disc, but a positive test may suggest the location of the displacement. If the disc is displaced medial to the nerve root within the "axilla" (between the spinal dura and exiting root sleeve) or directly beneath the nerve root, the test is more likely to be positive. A positive finding has also been reported to be indicative of a large or massive disc protrusion (Finneson 1980, MacNabb 1977, Woodhall and Hayes 1950). Finneson (1980) reported that raising the unaffected leg in patients with a protrusion lateral to the root might relieve root compression in the affected extremity. The WLR has been found to be positive in 87% of cases, and SLR, in 77% of cases confirmed at surgery (Hakleius & Hindmarsh 1972). The WLR has also been reported to be positive in 97% of patients who proved to have disc displacement at surgery (Hudgins 1977). Others report the test not to be as predictive. Sprangfort (1972) found the test to be positive in 23.2% of verified herniations, and Finneson (1980) while reporting the test to be "the single most reliable sign of disc herniation" when present, reported it to be positive in only 20-30% of herniations.

3. Spinal Range of Motion

Spinal range of motion was tested in three planes of movement: forward spinal flexion (Figure 11), lateral spinal flexion (Figure 12), and spinal extension (Figure 13) according to the method of Macrae and Wright (1969), and Moll and Wright (1971).

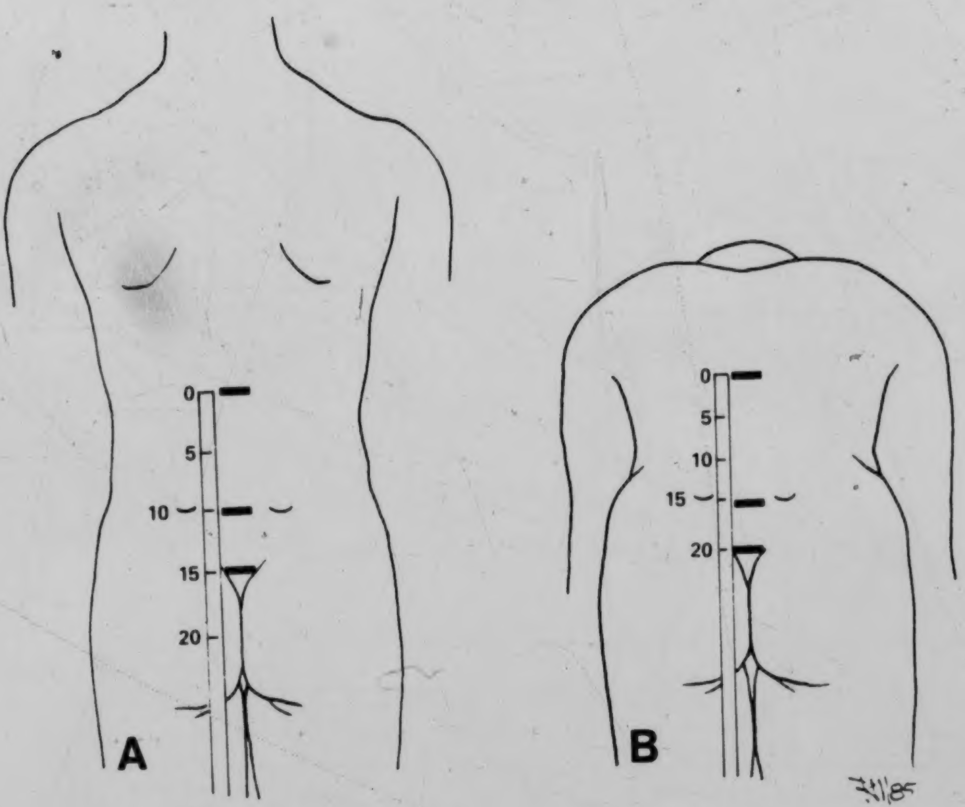

Figure 11. Measurement of Forward Flexion With Patient Erect (A), and Forward Flexed (B). The middle mark is placed at the posterior superior iliac spine, the upper mark 10 cm above, and the lower mark 5 cm below.

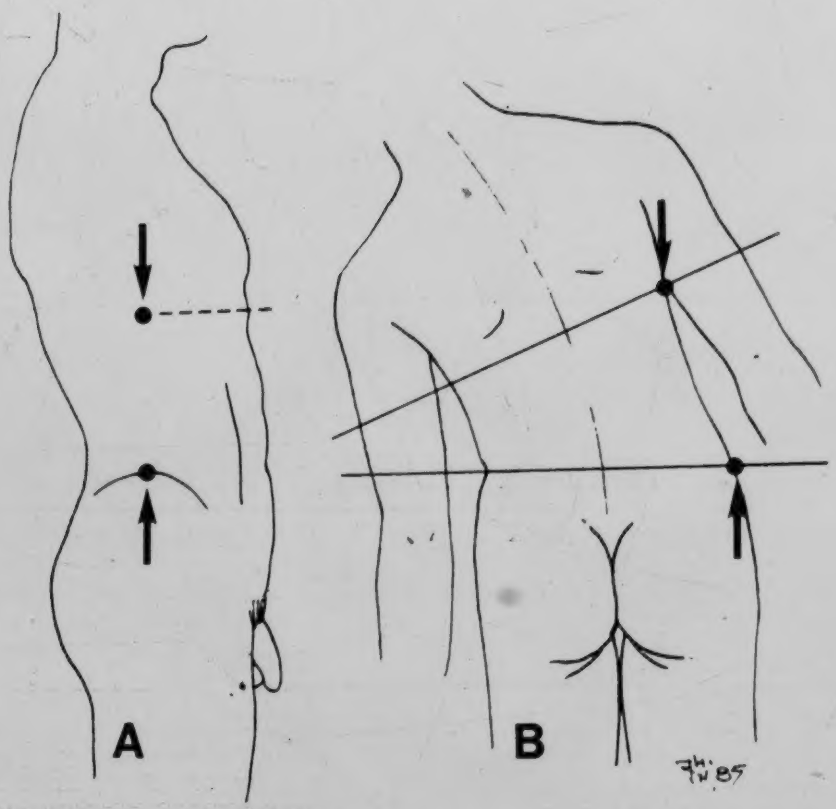

Figure 12. Measurement of Side Flexion With Patient Erect (A), and in Side Flexion (B). The upper mark is made at the intersection of a horizontal line through the xiphisternum with the coronal line. The lower mark is made at the highest point on the iliac crest.

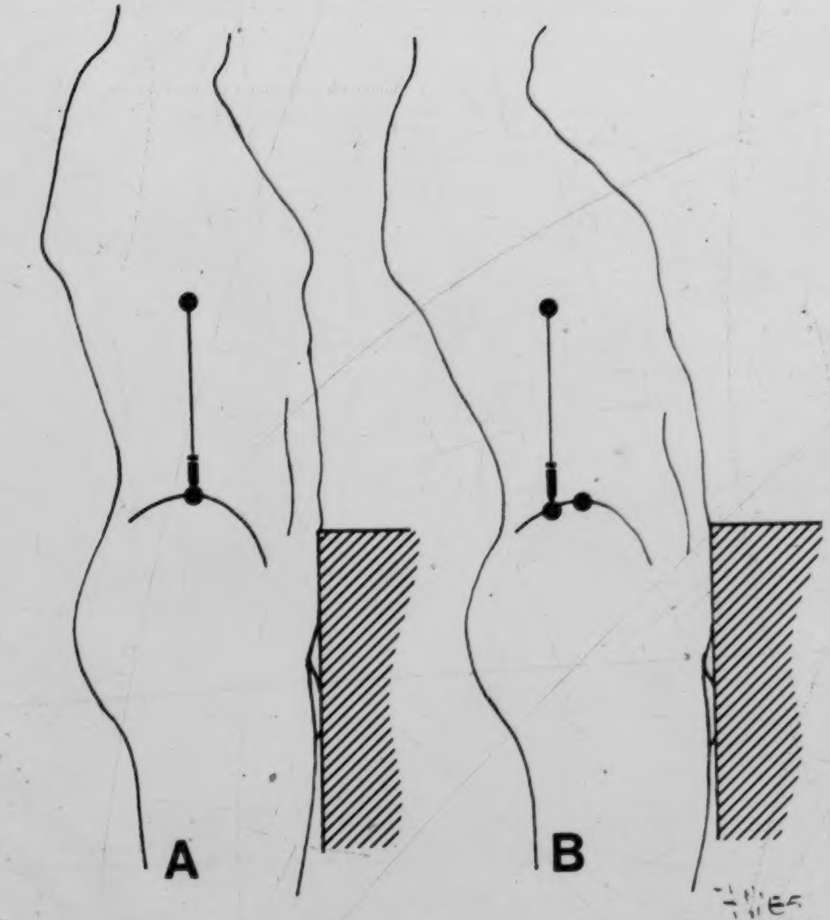

Figure 13. Measurement of Extension With Patient Erect (A), and Forward Flexed (B).

The upper mark is made at the intersection of a horizontal line through the xiphisternum with the coronal line. The lower mark is made at the highest point on the iliac crest.

The objective clinical methods of spinal mobility measurement were developed in order to quantify "limitation of motion of the lumbar spine" which was adopted as one of the clinical criteria for diagnosis of ankylosing spondylitis (Moll and Wright 1971). The methods were developed in order to facilitate comparison of the results of one study with another and to eliminate the subjectivity of one of the criteria for diagnosis of the condition. The tests are described in 'Materials and Methods'.

The methods of measurement of spinal motion were found to be simple to perform, reliable and applicable to clinical work (Moll et al. 1972a, 1972b, Macrae and Wright 1969).

a. Forward Flexion (Figure 11)

Macrae and Wright (1969) developed an objective test to measure forward flexion using skin distraction. The skin is well tethered over the coccyx and poorly tethered over the lumbar spine and sacrum. To determine the accuracy of the method, they placed lead markers over the skin marks, and lateral radiographs were taken with the patient standing erect, and in full forward flexion. The correlation with the radiological measurement of anterior spinal flexion was very high ($r=.97$, $P<.001$). Faulty placement of the skin marks, for example placing them 2 cm above or below the lumbosacral junction, had a negligible affect on this method of measurement.

The mean forward flexion (Moll and Wright 1971) for the normal 35-44 year olds was 6.88 cm for the males (range 5.70-8.50 cm), and for the females; 6.29 cm (range 3.80-8.30 cm).

b. Lateral Flexion (Figure 12)

Moll and Wright (1971) also described an objective method of measuring lateral flexion. Moll et al. (1972a) tested the accuracy of the measurement technique radiologically. The correlation between lateral flexion measured by skin distraction and the radiographs was high (r=.79, p<.001). In their study, intraobserver error was tested and the results reflected a high degree of intraobserver repeatability at 6.6% on the right and 6.1% on the left. Interobserver reliability was found to be moderately high (r=.68, p<.001).

The mean left lateral flexion in normal 35-44 year olds was 4.83 cm in males (range=2.70-5.90cm), and in females; 5.48 cm (range=2.70 to 8.00 cm). The mean right lateral flexion for this age group was 4.83 cm in males (range=2.50 to 7.50 cm), and 5.30 cm (range=3.10 to 7.80 cm) in females (Moll and Wright 1971).

c. Extension (Figure 13)

Direct measurement of spinal extension is not practical. The method of Moll et al. (1972b) was therefore devised in order to measure the distance indirectly by utilizing the pendulum principle. The method is based on the fact that linear excursion of the end of a flexible rod is related to its angle of displacement (Moll and Wright 1971).

Moll et al. (1972b) set up a spinal model of this system and found an almost perfect linear relationship between the angle of rod extension and the displacement distance at its free end ($r=+0.999$, $p<0.001$). The pendulum principle represented a useful measure of spinal extension.

Intraobserver error was calculated by Moll et al. (1972b) measuring extension in one subject on ten alternate days. The coefficient of variation for the measurement was 4.7% suggesting high intraobserver repeatability.

The interobserver error was calculated by comparing the measurements of two examiners. The correlation coefficient was high ($r=.93$, $p<.001$) showing a strong positive relationship between the observers.

The method was evaluated radiologically and a high association was found ($r=.75$, $p<0.01$) between the displacement of the lateral marks and the true angle of spinal extension. Using skin marks was a valid indication of thoracolumbar extension.

The normal range of extension in the 35-44 year olds was 3.73 cm in males (range=2.10-7.50 cm), and 3.09 cm (range=0.60 to 5.20 cm) in females. Age had a profound effect on decreasing extension (Moll and Wright 1971).

4. Present Pain Intensity Scale

The Present Pain Intensity (PPI) scale of the McGill Pain Questionnaire was utilized to assess the patient's subjective feelings of pain. The PPI scale is comprised of the following words and values: 0=no pain; 1=mild pain; 2=discomforting pain; 3=distressing pain; 4=horrible pain; 5=excruciating pain (Appendix B). The six words are arranged in order of intensity with the scale value of the words approximately equally spaced so as to represent equal scale intervals of pain intensity (Melzack and Togerson 1971). This scale has a very high correlation (r=.9) with the McGill Pain Questionnaire Pain Rating Index for percentage of change (Melzack 1975). The full McGill pain questionnaire is comprised of the PPI scale as well as a Pain Rating Index with a set of 78 verbal pain descriptors. The total number of words chosen is also taken into account. The McGill Pain Questionnaire has been found to be reliable and valid, sensitive enough to detect differences between various pain relieving techniques, and to provide quantitative information that can be statistically analyzed (Melzack 1975, Finch and Melzack 1982).

The PPI scale can be used for quantitative studies by analyzing the numbers associated with the words. The quantitative index could be used to indicate the change in quality and intensity of pain after a manipulative procedure by measuring the pain before and after the procedure.

It is a fast and simple measure to obtain, and is valid and reliable (Finch and Melzack 1982, Melzack 1975, Melzack et al. 1983).

CHAPTER III

MATERIALS AND METHODS

A. Preoperative and Postoperative Patient Assessment

The investigator was contacted at the time of the patient's admission. The study was explained to the patient and an informed consent obtained (Appendix C). The preoperative assessment for spinal ROM, SLR, WLR and pain was then performed (Appendix D).

Spinal Range of Motion

The patient was measured for spinal range of motion as described by Moll and Wright (1971), and Macrae and Wright (1969). All measurements were performed with a plastic metal ended tape measure and recorded in cm. For all spinal ROM tests, the patient was clad only in underwear and stood with the feet together in an erect stance.

Anterior spinal flexion was measured following marking the skin with a line in the region of the lumbosacral junction. The posterior superior iliac spines were palpated and marked at the dips directly distal to them and joined with a line. Palpation was used rather than the dimples of Venus to represent the lumbosacral junction as described by Moll and Wright (1973). The measurement was thus standardized because the dimples were not always present in all patients. A mark was made 5 cm below and 10 cm above the line joining the two marks (Figure 11). The subject was then asked to forward flex as far as possible, keeping the knees extended. The distance between the skin marks was measured, with the increase indicating the amount of forward flexion. The test was based on separation of the skin marks.

During lateral spinal flexion, the patient stood with the arms hanging vertically downwards at the sides. The pelvis was approximated to the examining couch in order to maintain the movement in the frontal plane. Two points were marked on the patient. The upper mark represented the intersection of a horizontal line through the xiphisternum with the coronal line, and the lower mark was made at the highest point on the iliac crest, at its intersection with the coronal line. The distance between the skin marks was measured. Due to fat folds developing in the lateral trunk complicating measurement, distraction of the skin marks on the contralateral trunk was used in all cases rather than approximation of marks on the homolateral trunk as described by Moll et al. (1972a). The subject was asked to bend sideways in the frontal plane by sliding a hand down the homolateral thigh. Patients were instructed to keep both knees straight and not to twist forwards or backwards while bending sidewards. They were instructed not to elevate the shoulders in attempting to maintain the required posture. At the end of this movement, the distance between the two marks on the contralateral side was measured, and the old distance subtracted from the new distance (Figure 12).

Extension was measured using the marks previously made for lateral flexion. A plumb bob was used on the end of a 20 cm thread. The plumbline point was held so it corresponded with the lower mark, while the thread with the upper mark. The subject stood erect with the hands behind the head and the elbows flexed in the frontal plane. The pelvis was approximated to the edge of the examination couch to avoid hip extension. The subject was asked to bend backwards as far as possible without bending the knees and deep inspiration was discouraged in order to prevent appreciable elevation of the upper skin mark. The distance travelled by the plumbline pointer was marked on the skin and measured in centimeters (Figure 13). The measurement was made on both the right and the left and averaged, as they have been reported to differ between the two sides (Moll et al. 1972b).

Straight Leg Raise

The straight leg raise (SLR) range of motion was recorded by the Leighton Flexometer® [2] (Figure 14), which is comprised of a weighted 360 degree dial and a weighted pointer in a case. The dial and pointer move independently of each other. The zero mark on the dial and the pointer tip move freely to a point of rest and each has an independent locking mechanism (Leighton 1955, Turner 1982).

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[2] Leighton Flexometer, East 1321-55 Avenue, Spokane, Washington, 99203

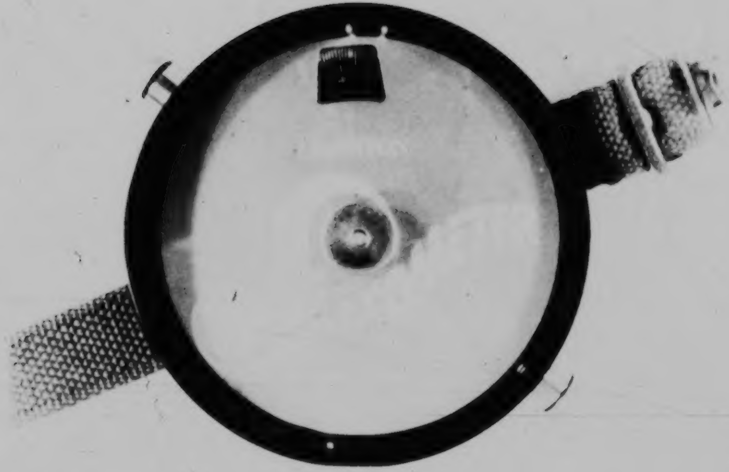

Figure 14. Leighton Flexometer

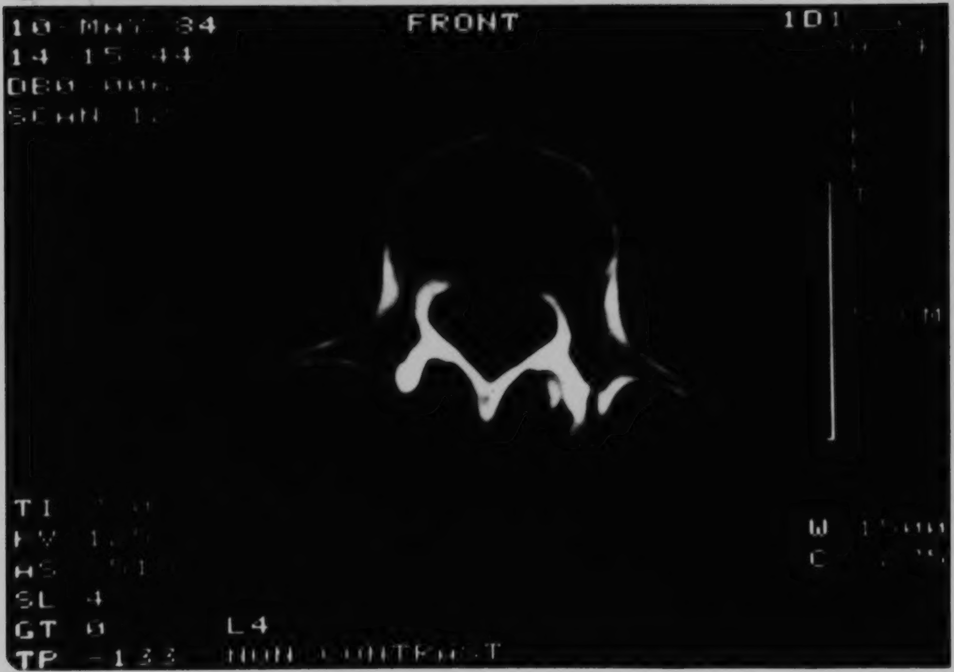
10-MAY-84
FRONT
101
14 15 44
TI
SL 4
GT 0
L4
TP -133
NON CONTRAST
W
C

Figure 15. CT Scan of a Triangular Shaped Canal

The patients were told that the limb would be lifted slowly by the investigator with the knee straight and without their assistance and that they would be asked to indicate the symptoms and their location during this manouver (Fahrni 1966, Urban, 1981). Each patient was examined in supine with the head and neck resting in neutral without a pillow. The arms were placed in the anatomical resting position. The trunk was straight without lateral flexion or rotation. The hips were neither adducted or abducted. The flexometer was strapped to the lateral thigh 10 cm proximal to the most proximal portion of the head of the fibula. The flexometer dial was locked at zero and the pointer indicated zero degrees. The examiner placed one hand on the knee of the side being tested to maintain it in full extension, and the other hand held the leg above the malleoli. The leg was raised into hip flexion passively and slowly, to avoid unnecessary pain, apprehension or a stretch reflex, maintaining the knee extended, the foot in a vertical plane, and rotational neutrality at the hip. The resting knee remained extended and in contact with the table. The leg was raised until the patient complained of pain. At this point, the flexometer pointer was locked and the ROM and site of symptoms recorded (Breig and Troup 1979, Ekstrand et al. 1982, Leighton 1955, (Scham and Taylor 1971, Speakman 1978, Sady et al. 1982, Troup et al. 1968, Turner 1982, Urban 1981). Use of the flexometer has been established for reliability (Hsieh 1983).

Hamstring tightness, a frequent obstacle to complete SLR was distinguished from reflex resistance secondary to radicular pain (Scham and Taylor 1971). Hamstring tightness was defined as a gradual tightening discomfort behind the knee which dorsiflexion of the foot would also cause behind the knee and in the calf. On the other hand, severe pain in the back, in the sciatic distribution of the affected leg, or both was due to nerve root pressure and was deemed positive (Finneson 1983).

Well Leg Raise

The well leg raising test was performed in the identical manner except that the unaffected leg was raised and had to be raised higher in order to produce identical symptoms when positive.

Present Pain Intensity

The Present Pain Intensity (PPI) scale of the McGill Pain Questionnaire was utilized to assess the patient's subjective feelings of pain. The words were read in the following order: no pain, mild, discomforting, distressing, horrible and excruciating (Appendix B). The patient was told to indicate one of the words in the scale to describe the pain at best, and at worst. The words were reread as many times as necessary until the patient reached a decision. The numerical value of the word was recorded for both pain at best, and pain at worst (Melzack 1975).

B. Computed Tomography Scan

Prior to surgery, a CT scan was completed. The type of machine used was a third generation scanner: a Somatom DR3®. The patient was positioned supine with about 45 degrees of hip flexion and 45 degrees of knee flexion. The hips and knees were immobilized with straps to prevent motion. The knees were flexed over a foam positioning block of 6 5/8 x 9 x 18 inches (GE E6423BH #124),[3] and the buttocks were elevated with a 7 cm positioning block. The hip and knee flexion helped to decrease the lumbar lordosis (Hirofugi 1983, Genant 1982, Ullrich 1980, Postacchini et al. 1980, Chafetz and Genant 1983). A lateral scout view (Figure 11) was obtained prior to scanning to provide anatomic localization and to determine the gantry angles necessary in order to maintain transverse orientation perpendicular to the long axis of the spine, especially at the L5-S1 disc (Roub 1979). Initially, continuous 4 mm thick slices at 3 mm intervals were taken with the gantry perpendicular to the long axis of the spine as much as possible. At the L4-L5 and L5-S1 discs, if the disc space was too narrow for these slices, 2 mm scans at 2 mm intervals were obtained with the gantry angled to provide as true axial images of the intervertebral disc as possible. The gantry was also angled if necessary for images parallel to superior end plate at the midpedicular level of the L4 and L5 vertebrae. Gantry angling was done in order to avoid obtaining incorrect measurements on cuts oblique to the long axis of the canal rather than perpendicular (Nachemson and Asztely 1981). Thus each patient's measurement was standardized as each slice was at the midpedicle and parallel to the superior end plate. The approximate time for examination was 45 minutes. If a metrizamide myelogram was done, it was done first, with the scan at least 2 hours afterwards. The contrast, if still present during the scan, did not affect the canal measurements.

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[3] General Electric Radiology Supplies and Accessories Reference, April, 1979

The milliamperage per second (MAS) was usually 518 MAS, with minor variations according to the patient size. One hundred and twenty five kilovolts (KV) were used. The scan time was 7 seconds.

A software targeting program using a DEC PDP 11/44 [4] computer processor, with a small pixel size of 1 mm (within the patient) for reconstruction and an edge enhancing convolution kernel (number 3) was used to give optimum evaluation of the bony canal (Chafetz and Genant 1983, Genant 1982, Siemens 1982). The images were photographed with a zoom factor of 4.5 times magnification. A window width of 1500 CT numbers and a bone window centre of 275 CT numbers was used. The window setting and zoom factor were kept constant while photographs were made in a cephalad to caudal direction. The scanner was calibrated before each patient (Siemens 1982) in order to ensure stability of the detector and to prevent ring artifacts (Chafetz and Genant

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[4] Digital Equipment Corporation, Maynard, Massachusetts, USA

1983, Genant 1982, Seeram 1982).

Measurement was taken at the midpedicle level where the canal was outlined entirely by bony structures (Figure 2): anteriorly by the posterior border of the vertebral body, posterolaterally by the pedicles, pars interarticularis and the laminae. The transverse processes were visible lateral to the pedicles and pars interarticularis (Chafetz and Genant 1983, Isherwood 1980, Postacchini 1980).

Measurement of the sagittal diameter was performed by placing the cursors at the midposterior surface of the vertebral body and the inner middle surface of the laminae and obtaining a readout on the image console (Figure 2).

The transverse measurement (Figure 2) was done at the greatest distance between the pedicles by placing cursors at the desired points and obtaining a readout of the distance between the points on the image console (Carrera et al. 1980, Helms and Volger 1982).

The cross-sectional area was measured using the irregular region of interest mode by tracing the region of interest with the electronic stylus. The area readout, in square centimeters, was displayed on the image console in the result field (Figure 5). If the measurement was not exactly on the bony interface, three measurements (within 0.10 cm^2) were made and the mean reported. The measurement readouts were the actual anatomical value after all magnification factors had been corrected for within the computer. All measurements were recorded on the CT data collection sheet (Appendix E).

Measurement was taken from a 512 matrix floppy disc where the information was copied to and stored. The scans were also stored on the hard magnetic disc as a backup. To obtain a hardcopy, a Multispot F Multiformat®[5] Camera was used (Siemens, 1982). Hard copies were made of all of the canal measurements so that they would be available for review. The shape of the canal was recorded as triangular (Figure 15), deltoid (Figure 16) or trefoil (Figure 17) There were no oval canals observed in this study (Baddeley 1976, Lee et al. 1978).

C. Surgical Technique

The following operative procedure used: A posterior midline incision was made and the paravertebral muscles were retracted at the level of the displaced disc. The ligamentum flavum was removed along with the adjoining laminar margins to expose the dura and nerve root. The nerve root was retracted medially and the disc lesion could thus be visualized. The findings were categorized as follows: 1. normal 2. disc protrusion with bulging annulus fibrosus 3. subligamentous disc prolapse (measured in mm) 4. disc extrusion 5. disc sequestration with migration of fragments (measured in mm) and 6. disc sequestration without migration of fragments (measured in mm).

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[5] Siemens Electric Limited, 9828-45 Avenue, Edmonton, Alberta, T6E 5C8

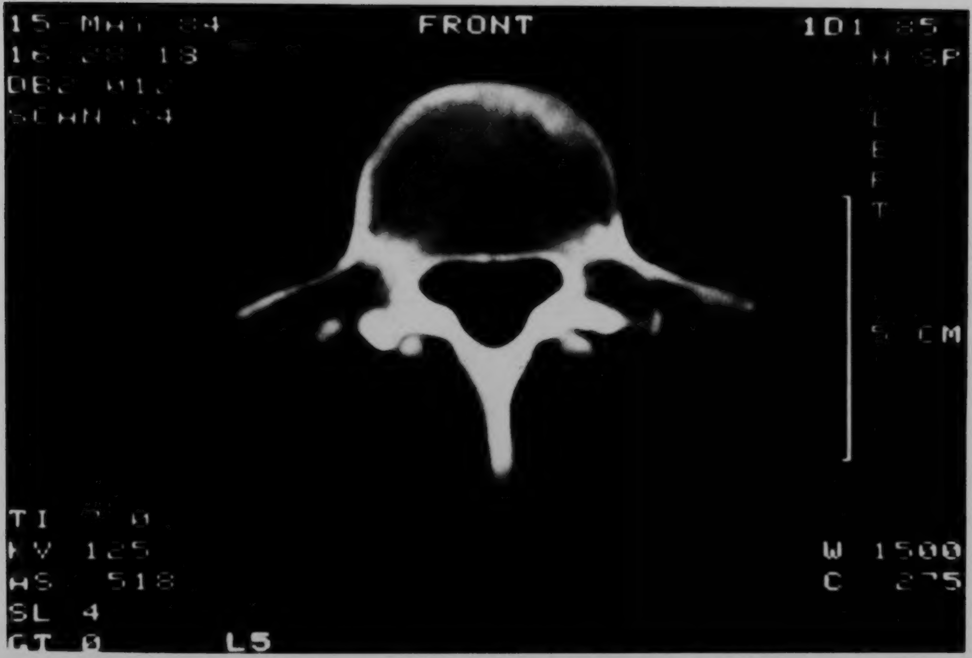
15-MAY-84
16 28 18
DB2 012
SCAN 24
FRONT
1D1 85
H SP
LEFT
5 CM
TI 7 0
KV 125
AS 518
SL 4
GT 0
L5
W 1500
C 275

Figure 16. CT Scan of a Deltoid Shaped Canal

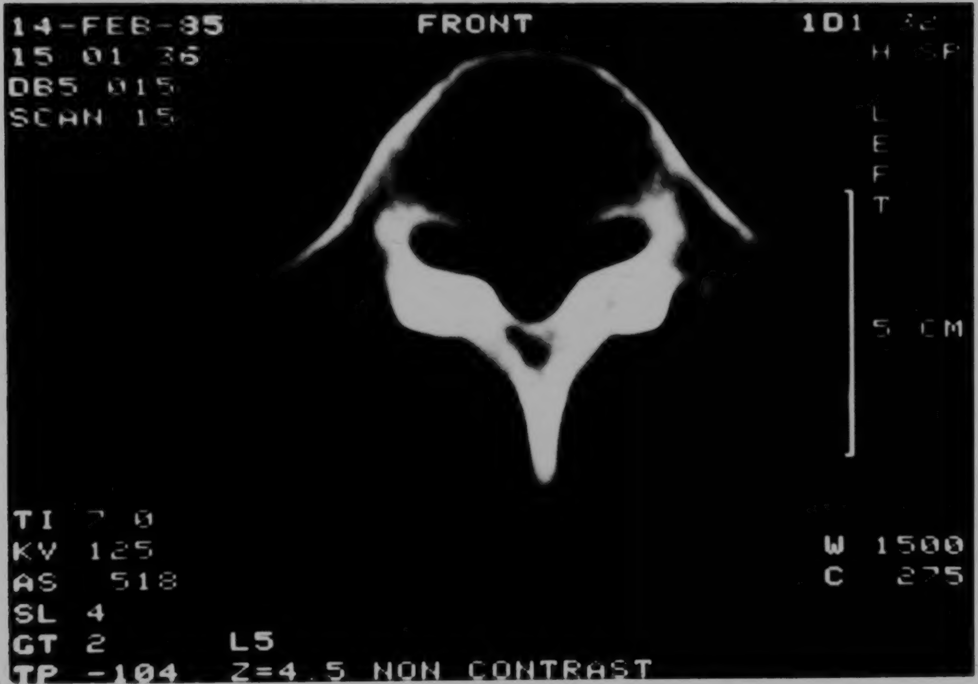
14-FEB-85
15 01 36
DB5 015
SCAN 15
FRONT
1D1 32
H SP
LEFT
5 CM
TI 7 0
KV 125
AS 518
SL 4
GT 2
L5
TP -104
Z=4.5 NON CONTRAST
W 1500
C 275

Figure 17. CT Scan of a Trefoil Shaped Canal

The posterior longitudinal ligament or annulus fibrosus was incised in a rectangular fashion to allow removal of the disc fragment(s). The disc space was evacuated thoroughly with disc nibblers through the incised rectangular defect, but not curretted. No attempt was made to repair the annulus. The defect in the spinal canal was covered with a piece of subcutaneous fat. Closure of the wound was made with dexon suture in layers.

D. Postoperative Routine

The day of surgery, the patient was on bed rest and took nothing orally and was on intravenous fluids. The first day postoperatively, the patient began assisted ambulation (Appendix F). If bowel sounds were present, the patient was started on oral fluids. On the second day postoperatively, the patient was taken to the hydrotherapy pool by stretcher, and was floated off the stretcher using a hoist for assistance. The patient then commenced walking, postural reeducation, and extension exercises for the trunk and lower extremities while in the pool. On the third day, the patient was taken to the pool by stretcher, sat up and walked into the pool. By the fourth postoperative day the patient either walked to the pool or went via the wheelchair. Pool therapy was not given over the weekend. Ambulation and pool exercises continued until the fifth to seventh postoperative day when the patient was usually discharged. Sitting was started at the second or third postoperative day for 5 to 10 minutes at a time and was increased slowly to pain tolerance. Prolonged sitting was discouraged. On discharge, the patient received an instruction sheet (Appendix A) regarding activities and was instructed to continue doing the exercises learned in the pool while at home. The patient was given the following analgesic medication if required: Tylenol 1, 2 or 3; codeine, demerol, morphine, or 292's. Some patients were given valium until discharge. No formal course of antiinflammatory medication was given. At six weeks, the patient returned to the surgeon for reevaluation. Prior to being examined by the physician, the investigator examined the patient to complete the six week postoperative evaluation (Appendix D).

E. Data Presentation and Analysis

The data collected for each subject was recorded on a data aquisition form (Appendix D). The raw data are listed in Appendix G. The .05 level of significance was adopted. However, due to the small number of subjects, in order to examine trends towards significance, the .10 level was also reported. Because the sample was small and not necessarily representative, inference could not be drawn to the disc lesion population in general. Therefore the magnitude of the relationships were more meaningful to examine than was the statistical significance.

The association between the canal measurements and the clinical findings was evaluated with Pearson product moment correlation (Pearson correlation) coefficients. Point biserial correlations were used for association of dichotomous with continuous variables (Fergusen 1981).

Differences between the means of the clinical variables for the three canal shapes were tested using one-way analysis of variance. The Eta^2 was examined for the amount of variance explained by canal shape (Norusis 1983).

To determine the proportion of variation (improvement) in the clinical parameters explained by the preoperative values, canal sizes and canal shapes, multiple regression was calculated. Multiple regression was chosen because it is used to analyze the relationship between a dependent or criterion variable and a set of independent or predictor variables (Kim and Kohout 1975). All statistical analysis was done using a computer SPSSx package[4].

F. Reliability Tests and Percent Error

In order to ensure the reliability of the investigator's canal measurements on the CT scanner, a radiologist also performed the measurements on the L4 vertebrae of 15 subjects (Appendix H). Pearson correlation coefficients were performed and found to be very high ($r=.96$ for the sagittal canal measurements; $r=.99$ for the transverse canal measurements; and, $r=1.0$ for the cross-sectional measurements). These values proved to be very highly significant ($p \leq .000$).

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[4] SPSSx User's Guide, A Complete Guide to Language and Operations, Spss Inc., Chicago, Illinois, USA, 1983

Ullrich et al. (1980) reported interobserver differences of 3% or less for linear measurements, and intrarater differences of 1%. Their cross-sectional measurements had an intrarater reliability of 4.5%.

Percent error was calculated in order to ensure the accuracy of the investigator's canal measurements. The same measurement was performed ten times on the same CT scan and the following results were obtained: 1.40% for the transverse canal diameter; 2.16% for the sagittal canal diameter; and 0.63% for the cross-sectional canal measurement. These values were below the 3% considered acceptable for research (Weber and Lamb 1970).

Percent error was also calculated to evaluate the accuracy of testing the clinical parameters. All tests were performed ten times on the same subject on the same day (Appendix H). The SLR result using the Leighton flexometer® was 2.93%, and the forward flexion: 3.79%. The extension value was 5.00% which compared closely to Moll et al. (1972b) who reported a "coefficient of variation" in extension of 4.7% when measuring the same subject on ten alternate days. They reported their value to have high intraobserver repeatability.

Side flexion had percent error values of 5.50% for the right and 2.86% for the left. This value compared favourably with Moll et al. (1972a) who tested the lateral flexion in the same patient on ten successive days. Their values were 6.6% on the right and 6.1% on the left. Spinal ROM values, tended to increase with repeated measurements as the tissues became more extensible. Because the investigator was not measuring a static value, rather a changing physiologic parameter, the larger percent error than those of the CT scans were more likely due to the patient's own variation than the investigator's inacurracy.

G. Calibration

The Somatom DR3® was calibrated prior to each patient's scan as described by Siemens (1982).

CHAPTER IV

RESULTS

Twenty patients, aged 24 to 56 years, with displaced discs at L4-5 or L5-S1 were examined preoperatively and postoperatively, and selected physical measurements were compared to their CT scans.

The mean age of the twenty subjects was 36 years (SD=9.6) with a range of 24 to 56 years. Thirteen patients had L5-S1 discectomies, and seven had L4-L5 discectomies. There were fifteen males and five females in the study.

One male patient, with an L4-L5 lesion, developed a postsurgical discitis, and at the six week postoperative examination had been rehospitalized. Analysis was therefore computed on twenty patients preoperatively and nineteen patients postoperatively as this patient's values did not indicate how he would have done without the complication. His preoperative data was used and his postoperative values coded as missing data[7]. On reexamining this patient at a one year followup, his result was excellent.

The L4-L5 and L5-S1 disc patients were grouped together because the transverse and AP diameters have been reported to have no significant difference at these levels (Weir 1979). Canal shapes are also similar at these levels

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[7] SPSSx User's Guide, A Complete Guide to Language and Operations, Spss Inc., Chicago, Illinois, USA, 1983

(Baddeley 1976). Males and females were grouped together as their canal measurements have been found not to differ significantly at these levels (Hinck 1966, Winston et al. 1984). In order to test whether there was a significant difference between the L4-L5 and L5-S1 patients at the two levels, t tests, or Fisher exact tests were calculated depending on whether the variables were continuous or dichotomous. Sex, age, canal measurements, and the clinical variables were tested. In all but one case, the two groups were found to be homogenous. In the postoperative extension group, however, there was a significant difference between the means ($p \leq .05$). Statistical analysis of postoperative extension was therefore done on the two levels grouped together, and on the two levels separately where possible.

The results of the study refer to the canal sizes and shapes as the independent variables, and the clinical parameters as the dependent variables. The raw data for the variables measured are found in Appendix G.

There were nine triangular canals (45%), six deltoid canals (30%), and five trefoil canals (25%). None of the canals were classified as oval. The patient whose postoperative data was not used had a deltoid shaped canal. The frequencies of canal shapes are listed in Table 6.

Table 6

Canal Shape Classification
(n=20)

CANAL SHAPE	FREQUENCY	PERCENT(%)
OVAL	0	00%
TRIANGULAR	9	45%
DELTOID	6	30%
TREFOIL	5	25%
TOTAL	20	100%

The average sagittal canal diameter was 17 mm (SD=2.0) ranging from 13 to 23 mm; the average transverse canal diameter was 29 mm (SD=4.0) with a range of 23 to 40 mm; and the average cross-sectional area was 3.43 cm^2 (SD=0.62), ranging from 2.72 to 5.34 cm^3. Table 7 lists the mean, standard deviation and range of the canal measurements.

Table 7

Mean, Standard Deviation, and Range of Sagittal, Transverse and Cross-sectional Canal Measurements (n=20)

VARIABLE	MEAN	SD	MIN	MAX	UNITS
SAGITTAL	17.00	2.00	13.00	23.00	mm
TRANSVERSE	29.00	4.00	23.00	40.00	mm
CROSS SECTION	3.43	0.62	2.72	5.34	cm^2

Pain at best before surgery was on average between 'mild' and 'discomforting', (ranging from 'no pain' to 'discomforting'), and after surgery, pain at best averaged between 'no pain' and 'mild pain', (ranging from 'no pain' to 'discomforting'). Pain at worst before surgery averaged 'excruciating', (ranging from 'discomforting' to 'excruciating'), and postoperatively pain at worst was on average 'discomforting', (ranging from 'mild' to 'excruciating', Appendix B).

Table 8 describes the mean, range and standard deviation for the leg raise tests. The average SLR before surgery was 29 degrees (SD=18), ranging from 10 to 65 degrees, and postoperatively, the mean SLR was 60 degrees (SD=13), with a range of 40 to 90 degrees. Nineteen straight leg raise tests (95%) were positive preoperatively and one

(5%) was negative. Postoperatively, of the 19 patients measured, fifteen (79%) were negative and four (21%) were positive (Table 9).

The average WLR preoperatively was 52 degrees (SD=18), ranging from 25 to 85 degrees. After surgery, the mean had increased to 65 degrees (SD=12), ranging from 30 to 85 degrees. There were sixteen (80%) positive well leg raise tests preoperatively, and four (20%) were negative. Postoperatively, eighteen (95%) of the well leg raise tests were negative, and one (5%) was positive (Table 9).

Table 8

Mean, Standard Deviation and Range for Straight Leg Raise, and Well Leg Raise (in Degrees) (n=20 Preop, n=19 Postop)

VARIABLE	MEAN	SD	MIN	MAX
SLR PREOP	29	18	10	65
SLR POSTOP	60	13	40	90
WLR PREOP	52	18	25	85
WLR POSTOP	65	12	30	85

Table 9

Frequency of Occurrence of Positive and Negative
Straight Leg Raise and Well Leg Raise Tests (in %)
(n=20 Preop, n=19 Postop)

VARIABLE	POSITIVE	%	NEGATIVE	%
SLR PREOP	19	95%	1	5%
SLR POSTOP	4	21%	15	79%
WLR PREOP	16	80%	4	20%
WLR POSTOP	1	5%	18	95%

The average forward flexion before surgery was 2.5 cm (SD=1.8) with a range of 0 to 6.5 cm, and after surgery, the mean improved to 4.3 cm (SD=1.3), ranging from 2 to 6.5 cm.

The average extension before surgery was 2.9 cm (SD=1.8), ranging from 0 to 7 cm, and postoperatively, the mean was 3 cm (SD=0.8), ranging from 2 to 5 cm. Separating the two levels, the mean at L4-L5 was 2.2 cm (SD=0.3) with a range of 2 to 2.8 cm, and at L5-S1 the mean was 3.3 cm (SD=0.8) ranging from 2.5 to 5.0 cm.

Right side flexion had a mean of 4.3 (SD=2.1) before surgery, ranging from 0 to 9 cm, and postoperatively, the mean was 4.6 cm (SD=1.5), ranging from 2 to 7 cm.

Left side flexion averaged 4.7 cm (SD=2.7) preoperatively, ranging from 0 to 10 cm. After surgery, the mean increased to 5.4 cm (SD=1.5), ranging from 2.5 to 8.0 cm.

Table 10 includes the mean, standard deviation and range for the spinal range of motion variables.

Table 10

Mean, Standard Deviation and Range For Forward Flexion Extension, Right Side Flexion and Left Side Flexion (in cm) (n=20 Preop, n=19 Postop)

VARIABLE	MEAN	SD	MIN	MAX
FLEX PREOP	2.5	1.8	0.0	6.5
FLEX POSTOP	4.3	1.3	2.0	6.5
EXT PREOP	2.9	1.8	0.0	7.0
EXT POSTOP				
Group	3.0	0.8	2.0	5.0
L4-L5	2.2	0.3	2.0	2.8
L5-S1	3.3	0.8	2.5	5.0
RFLEX PREOP	4.3	2.1	0.0	9.0
RFLEX POSTOP	4.6	1.5	2.0	7.0
LFLEX PREOP	4.7	2.7	0.0	10.0
LFLEX POSTOP	5.4	1.5	2.5	8.0

Pearson correlation coefficients were calculated in order to determine the degree of association between the three canal measurements. The canal cross section had significant positive relations with the sagittal and tranverse measurements (p≤.01). The correlations are listed in Table 11.

Table 11

Pearson Correlation Coefficients Between Sagittal, Transverse and Cross-sectional Canal Measurements (n=20)

	SAGITTAL	TRANSVERSE
CROSS SECTION	0.64* (p≤.001)	0.57* (p≤.004)
TRANSVERSE	-0.16 (p≤.245)	

*denotes p=≤.01

Table 12 lists the group correlation coefficients between the canal measurements and the pain at best, and pain at worst. No significant association was found and all of the correlations squared were small and the largest amount of variance shared was 8%.

Table 12

Pearson Correlation Coefficients of Sagittal, Transverse and Area Measurements With Pain at Best and at Worst (n=20 Preop, n=19 Postop)

CLINICAL VARIABLES	SAGITTAL	TRANSVERSE	AREA
PAIN AT BEST PREOP	-.28 (p≤.116)	-.07 (p≤.393)	-.14 (p≤.285)
PAIN AT BEST POSTOP	-.18 (p≤.225)	.09 (p≤.358)	.04 (p≤.433)
PAIN AT WORST PREOP	-.01 (p≤.482)	.22 (p≤.177)	.21 (p≤.186)
PAIN AT WORST POSTOP	-.25 (p≤.150)	.03 (p≤.456)	-.04 (p≤.437)

Table 13 lists the Pearson correlation of canal measurements with the leg raise tests in degrees. All of the correlations and correlations squared were small and no significant association was found. The maximum amount of variance shared was 6%.

Table 13

Pearson Correlation Coefficients of Sagittal, Transverse and Area Measurements With Leg Raise Tests (in Degrees) (n=20 Preop, n=19 Postop)

VARIABLE	SAGITTAL	TRANSVERSE	AREA
SLR PREOP	-.16 ($p \leq .256$)	-.04 ($p \leq .440$)	-.18 ($p \leq .217$)
SLR POSTOP	.06 ($p \leq .402$)	-.13 ($p \leq .299$)	-.24 ($p \leq .158$)
WLR PREOP	-.25 ($p \leq .148$)	.07 ($p \leq .391$)	-.20 ($p \leq .204$)
WLR POSTOP	.09 ($p \leq .362$)	-.05 ($p \leq .420$)	-.14 ($p \leq .284$)

Point biserial correlations of the SLR and WLR (positive or negative) with the canal measurements are reported in Table 14. The preoperative SLR had a significant positive relationship with the sagittal canal diameter ($p \leq .05$) with 16% of the variance shared. This relationship was likely spurious. The postoperative WLR had a negative relationship with the transverse canal diameter which approached significance ($p \leq .10$) with 10% of the variance shared.

Table 14

Point Biserial Correlation Coefficients of Sagittal, Transverse, and Area Measurements With Leg Raise Tests (Positive or Negative) (n=20 Preop, n=19 Postop)

VARIABLE	SAGITTAL	TRANSVERSE	AREA
SLR PREOP	.40** (p≤.04)	-.04 (p≤.429)	.19 (p≤.209)
SLR POSTOP	-.10 (p≤.343)	.30 (p≤.105)	.20 (p≤.201)
WLR PREOP	.26 (p≤.130)	-.16 (p≤.256)	-.02 (p≤.474)
WLR POSTOP	.11 (p≤.332)	-.31* (p≤.098)	-.12 (p≤.312)

*denotes p≤.10
**denotes p≤.05

Table 15 lists the Pearson correlations of the spinal ranges of motion with the canal measurements. Postoperative extension at L4-L5 had a very large association with the sagittal canal, with 88% of the variance shared; and with the canal area, with 52% of the variance shared. Postoperative right and left flexion shared 16% and 18% of the variance respectively with the transverse canal. Left and right flexion had negative associations with the sagittal canal diameter and canal area.

Table 15

Pearson Correlation Coefficients of Sagittal, Transverse and Cross-Sectional Area With Spinal Forward Flexion, Extension, Right and Left Side Flexion (in cm)
(n=20 Preop, n=19 Postop)

CLINICAL VARIABLE	SAGITTAL	TRANSVERSE	AREA
FLEXION PREOP	-.21 (p≤.192)	-.14 (p≤.280)	-.24 (p≤.155)
FLEXION POSTOP	.04 (p≤.431)	.20 (p≤.202)	.20 (p≤.201)
EXTENSION PREOP	-.21 (p≤.184)	-.14 (p≤.285)	-.35* (p≤.067)
EXTENSION POSTOP			
Group	-.18 (p≤.224)	.21 (p≤.194)	-.09 (p≤.364)
L4-L5	.94*** (p≤.002)	.05 (p≤.462)	.72** (p≤.045)
L5-S1	.24 (p≤.214)	-.34 (p≤.127)	-.18 (p≤.272)
RIGHT FLEXION PREOP	-.27 (p≤.123)	-.20 (p≤.195)	-.39** (p≤.044)
RIGHT FLEXION POSTOP	-.24 (p≤.160)	.40** (p≤.047)	-.01 (p≤.489)
LEFT FLEXION PREOP	-.34* (p≤.073)	-.06 (p≤.400)	-.36* (p≤.061)
LEFT FLEXION POSTOP	-.38** (p≤.055)	.42** (p≤.037)	-.08 (p≤.379)

*denotes p≤.10
**denotes p≤.05
***denotes p≤.01

One-way analysis of variance was utilized to evaluate the differences between the means of the clinical variables for the three canal shape groups. All analysis of variance tables report the the group means of the clinical variables for the triangular, deltoid and trefoil canals, the F ratio, significance, and the Eta^2.

Table 16 lists the analysis of variance for the pain variables. There was little difference between the group means and none of the differences were significant and the Eta^2 were very small.

Table 16

One-Way Analysis of Variance for Comparison of Canal
Shape Means in Pain at Best and Pain at Worst
(n=9 Triangular 6 Deltoid 5 Trefoil Preop)
(n=9 Triangular 5 Deltoid 5 Trefoil Postop)

VARIABLE		TRIANG	DELTOID	TREFOIL	F	SIG	ETA^2
BEST PREOP	$\bar{x}$	1.56	1.33	1.60	.24	.79	.03
	SD	0.73	0.52	0.89			
BEST POSTOP	$\bar{x}$	0.56	0.40	0.40	.11	.90	.01
	SD	0.73	0.89	0.55			
WORST PREOP	$\bar{x}$	4.67	4.83	4.40	.44	.65	.05
	SD	0.50	0.41	1.34			
WORST POSTOP	$\bar{x}$	2.11	2.40	1.80	.34	.71	.04
	SD	1.05	1.67	0.45			

Table 17 reports the one-way analysis of variance used to compare the canal shape means in the SLR and WLR. Again, none of the differences between the canal shapes were significant and the Eta^2 were very small.

Table 17

One-Way Analysis of Variance for Comparison of Canal Shape Means in Leg Raise Tests
(n=9 Triangular 6 Deltoid 5 Trefoil Preop)
(n=9 Triangular 5 Deltoid 5 Trefoil Postop)

VARIABLES		TRIANG	DELTOID	TREFOIL	F	SIG	ETA^2
SLR PRE	$\bar{x}$	27	31	29	.06	.94	.01
	SD	17	19	23			
SLR POST	$\bar{x}$	59	60	60	.004	.99	.001
	SD	16	10	14			
WLR PRE	$\bar{x}$	50	50	59	.43	.66	.05
	SD	18	14	25			
WLR POST	$\bar{x}$	62	67	68	.46	.64	.05
	SD	15	10	10			

The one-way analysis of variance for spinal ROM values are listed in Table 18. The analysis could not be calculated on the L4-L5 postoperative extension as there were only triangular shaped canals in this group. Postoperative extension, right and left side flexion were found to have significantly different group means ($p \leq .05$).

Table 18

One-Way Analysis of Variance for Comparison of Canal
Shape Means in Spinal Range of Motion (in cm)
(n=9 Triangular 6 Deltoid 5 Trefoil Preop)
(n=9 Triangular 5 Deltoid 5 Trefoil Postop)

ROM		TRIANG	DELT	TREFOIL	F	SIG	ETA^2
FLEX PRE	$\bar{x}$	2.61	2.92	1.90	0.42	.66	.05
	SD	1.95	2.03	1.43			
FLEX POST	$\bar{x}$	4.11	4.70	4.30	0.32	.73	.04
	SD	1.27	1.44	1.26			
EXT PRE	$\bar{x}$	2.36	3.45	3.15	0.75	.49	.08
	SD	1.41	2.04	2.11			
EXT POST							
Group	$\bar{x}$	2.44	3.60	3.25	5.32*	.02	.40
	SD	0.50	1.01	0.60			
L4-L5	$\bar{x}$	2.21	-----	-----			
	SD	0.29	-----	-----			
L5-S1	$\bar{x}$	2.91	3.60	3.25	0.77	.49	.13
	SD	0.52	1.01	0.55			
RFLEX PRE	$\bar{x}$	3.61	5.75	3.80	2.25	.13	.20
	SD	1.62	2.32	2.28			
RFLEX POST	$\bar{x}$	3.61	5.40	5.60	5.38*	.02	.40
	SD	1.08	1.64	1.14			
LFLEX PRE	$\bar{x}$	3.67	6.08	5.00	1.61	.23	.16
	SD	2.12	2.62	3.30			
LFLEX POST	$\bar{x}$	4.28	6.10	6.70	10.43**	.001	.57
	SD	0.94	1.43	0.67			

*denotes p=≤.05
**denotes p=≤.01

The critical F ratio for the preoperative values was 3.55 at the .05 level (6.01 at the .01 level), with two degrees of freedom between groups and seventeen degrees of freedom within groups. The critical F ratio for the postoperative values was 3.63 at the .05 level (6.23 at the .01 level), with two degrees of freedom between groups and sixteen degrees of freedom within groups.

Scheffé tests were completed on the significant variables to determine between which of the three groups the difference was located. Table 19 lists the significant Scheffé tests. For postoperative extension, the triangular group mean was significantly different from the deltoid group mean. In postoperative right side flexion, the triangular group differed significantly from the trefoil group. For postoperative left side flexion, the triangular group means was significantly smaller than the deltoid and trefoil group means ($p=\leq .05$).

Table 19

Scheffé Tests for Differences Between the Means in Postoperative Extension and Postoperative Right and Left Side Flexion (n=19)

	GROUP MEAN			
VARIABLE	TRIANG	DELTOID	TREFOIL	SIGNIFICANCE
EXTENSION	2.44	3.60	3.25	*Triangle vs deltoid
RIGHT FLEX	3.61	5.40	5.60	*Triangle vs trefoil
LEFT FLEX	4.28	6.10	6.70	*Triangle vs deltoid *Triangle vs trefoil

*denotes $p \leq .05$

Multiple regression was then calculated to determine the proportion of variation in the postoperative variables explained by the preoperative values, canal sizes and canal shapes. The preoperative score and the canal measurements and shapes were used as predictors (independent variables) for the postoperative score (dependent variable).

First the correlations between the preoperative and postoperative variables were calculated. The correlation coefficients were squared in order to determine the variation in the postoperative score explained by the preoperative score.

The pain variables showed little association between the preoperative and postoperative values, and negligible association with spinal canal size or shape on improvement, so were not described in the regression analysis.

The flexion correlation was very low (r=.13) and on examining the scatterplot it became obvious that this minimal association was due to three outliers (patients 8, 14 and 20). When the correlation was recalculated with the three outliers excluded, it proved to be much higher at .57 with a correlation squared of .33.

The two levels of spinal extension were not analyzed separately as splitting the sample into two levels made the regression scores unfeasible due to the small sizes of the groups. Table 20 lists the correlations of the preoperative with the postoperative values for each variable, the correlations squared, and the significance.

Table 20

Pearson Correlation Coefficients (r) and Correlations Squared (r^2) Between the Preoperative and Postoperative Scores (n=20 Preop, n=19 Postop)

ROM	r	r^2	SIG
PAIN AT BEST	.14	.020	.28
PAIN AT WORST	.12	.013	.32
SLR (DEGREES)	.33	.106	.09
WLR (DEGREES)	.46	.211	.02
FLEXION	.13	.017	.29
Without Outliers	.57	.329	.01
EXTENSION			
Group	.32	.104	.09
L4-L5	.15	.023	.39
L5-S1	.33	.109	.13
RIGHT FLEXION	.54	.286	.01
LEFT FLEXION	.49	.239	.02

The final stage of the data analysis was the addition of canal size and then canal shape into the regression equation to determine the proportion of variation in the clinical parameters which they explained.

The variation accounted for by the addition of the sagittal canal and then shape in the postoperative clinical parameters is reported in Table 21. Except for left side flexion, addition of the sagittal diameter did not increase the variation explained by the preoperative value significantly.

Table 21

Variation Explained (%) in the Clinical Parameters by the Preoperative Value (r^2), and the Addition of the Sagittal Canal and Shape (R^2) (n=20 Preop, n=19 Postop)

VARIABLE	r^2	+SAG R^2	+SHAPE R^2
SLR (DEGREES)	.106	.119	.122
WLR (DEGREES)	.211	.255	.337
FORWARD FLEXION	.017	.023	.079
EXTENSION	.104	.115	.478
RIGHT FLEXION	.286	.295	.604
LEFT FLEXION	.239	.287	.644

All regression tables reported include the slope (B), standard error (SE B), beta, correlation (r) of the preoperative with the postoperative value, multiple correlation (R^2) with the canal size and the canal shape, F ratio (F), and significance (p).

Addition of the sagittal canal increased the variation in postoperative left side flexion explained by the preoperative value from 24% to 29%. Table 22 lists the regression analysis with the addition of the sagittal canal. The sagittal canal explained a decrease in the left flexion which approached significance ($p \le .07$). This negative effect, however, only amounted to about half of the positive effect of the preoperative value.

Table 22

Multiple Regression for the Amount of Variation in Postoperative Left Flexion Explained by the Sagittal Canal (n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
LEFT FLEX PREOP	.228	.127	.405	.49
SAGITTAL CANAL	-.146	.139	-.236	-.38
CONSTANT	6.823	2.640		

$R^2 = .287$ $F = 3.23$ $p \le .07$

Addition of the canal shape to the sagittal canal in the regression analysis did not explain any increased variation in the SLR or in flexion (Table 21). It did, however, explain an increased proportion of variation in the postoperative WLR, extension, and right and left side flexion.

The variation in the WLR increased from 25% to 34%. This effect was small and not significant ($p \leq .19$).

Table 23 reports the effect of adding shape to the sagittal canal in the extension regression equation. The variation explained increased significantly ($p \leq .05$) from 12% to 48%.

Table 23

Multiple Regression for the Amount of Variation in Postoperative Extension Explained by the Sagittal Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
EXT PREOP	.142	.109	.262	.32
SAGITTAL	.068	.077	.199	-.18
DELTOID	1.258	.414	.693	.48
TREFOIL	.838	.411	.461	.22
CONSTANT	.872	1.480		

$R^2=.479$ $F=3.21$ $p \leq .05$

Table 24 reports the significant effect of adding shape to the sagittal canal on the right flexion variable. The proportion of right flexion explained increased from 30% to 60% ($p \leq .01$).

Table 24

Multiple Regression for the Amount of Variation in Postoperative Right Flexion Explained by the Sagittal Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
R FLEX PREOP	.361	.137	.493	.54
SAGITTAL	.111	.125	.174	-.24
DELTOID	1.365	.702	.403	.32
TREFOIL	2.156	.663	.636	.40
CONSTANT	.290	2.434		

$R^2=.603$ $F=5.34$ $p\leq.01$

Table 25 shows the significant influence of adding shape to the sagittal canal in left side flexion. The variation accounted for in left flexion increased from 29% to 64% ($p\leq.01$).

Table 25

Multiple Regression for the Amount of Variation in Postoperative Left Flexion Explained by the Sagittal Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
L FLEX PREOP	.171	.098	.303	.49
SAGITTAL	.020	.115	.032	-.38
DELTOID	1.521	.630	.466	.29
TREFOIL	2.236	.610	.685	.54
CONSTANT	3.293	2.224		

$R^2=.644$ $F=6.33$ $p\leq.01$

The amount of variation in the clinical variables explained by the transverse canal is listed in Table 26. Addition of the transverse canal had little effect on increasing the variation explained in the SLR, WLR or forward flexion. The transverse canal had a small effect on extension which was not significant. Variation in right and left flexion were significantly increased by the addition of the transverse canal into the regression equation.

Table 26

Variation Explained (%) in the Clinical Variables by
the Preoperative Value (r^2), and the Addition
of the Transverse Canal and Canal Shape (R^2)
(n=20 Preop, n=19 Postop)

VARIABLE	r^2	+TRANS R^2	+SHAPE R^2
SLR (DEGREES)	.106	.118	.136
WLR (DEGREES)	.211	.216	.295
FORWARD FLEXION	.017	.069	.102
EXTENSION	.104	.160	.464
RIGHT FLEXION	.286	.533	.594
LEFT FLEXION	.239	.425	.652

Table 27 reports the significant effect of adding the transverse canal to the right flexion parameter. The variation accounted for in right flexion increased from 29% (accounted for by the preoperative value), to 53% ($p \leq .01$).

Table 27

Multiple Regression for the Amount of Variation in Postoperative Right Flexion Explained by the Transverse Canal
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
RIGHT FLEX PREOP	.456	.127	.623	.54
TRANSVERSE	.184	.063	.504	.40
CONSTANT	-2.706	2.039		

R^2=.533 F=9.13 p≤.01

Table 28 reports the addition of the transverse canal to the variation in left flexion explained by the preoperative value. The variation increased from 24% to 43% (p≤.01).

Table 28

Multiple Regression for the Amount of Variation in Postoperative Left Flexion Explained by the Transverse Canal (n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
LEFT FLEX PREOP	.281	.107	.499	.49
TRANSVERSE CANAL	.152	.067	.431	.42
CONSTANT	-.350	2.051		

$R^2=.425$ F=5.91 $p \leq .01$

Addition of the canal shape to the transverse canal did not explain any more variation in the SLR or flexion (Table 26). There was a small insignificant effect on WLR ($p \leq .26$). The variation explained did increase markedly in the extension and side flexion variables.

Table 29 reports the addition of shape to the transverse canal in extension. While the transverse canal increased the variation explained from 10% to 16%, the additional of canal shape significantly further increased this variation to 46% ($p \leq .05$).

Table 29

Multiple Regression for the Amount of Variation in Postoperative Extension Explained by the Transverse Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
EXT PREOP	.095	.117	.175	.32
TRANSVERSE	-.040	.063	-.204	.21
DELTOID	1.248	.442	.687	.48
TREFOIL	1.028	.637	.566	.22
CONSTANT	3.280	1.812		
	$R^2=.464$	F=3.03	$p \leq .05$	

Table 30 reports the addition of canal shape to the transverse canal for the right side flexion variable. Addition of canal shape significantly increased the variation accounted for from 53% to 59% ($p \leq .01$).

Table 30

Multiple Regression for the Amount of Variation in Postoperative Right Flexion Explained by the Transverse Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
R FLEX PREOP	.374	.146	.511	.54
TRANSVERSE	.068	.102	.186	.40
DELTOID	.861	.798	.254	.32
TREFOIL	1.411	.988	.417	.40
CONSTANT	.452	2.975		

$R^2=.594$ F=5.13 $p\leq.01$

Table 31 reports the addition of shape into the left flexion regression equation. The transverse canal increased the variation accounted for from 24% to 42%. The addition of shape significantly increased the variation explained to 66% ($p\leq.01$).

Table 31

Multiple Regression for the Amount of Variation in Postoperative Left Flexion Explained by the Transverse Canal and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
L FLEX PREOP	.147	.100	.261	.49
TRANSVERSE	-.054	.089	-.153	.42
DELTOID	1.698	.684	.520	.29
TREFOIL	2.628	.906	.805	.54
CONSTANT	5.171	2.537		
	$R^2=.653$	$F=6.57$	$p\leq.01$	

The variation explained by the preoperative value and the addition of the canal cross section and canal shape are reported in Table 32.

The canal cross section added little to the variation explained by the preoperative value in any of the clinical parameters. The addition of canal shape to the regression equation added little to the SLR, WLR or forward flexion variables. Shape did increase the amount of variation explained in extension, right and left side flexion.

Table 32

Variation Explained (%) in the Clinical Variables by the Preoperative Values(r^2), and the Addition of Canal Cross Section and Canal Shape (R^2)
(n=20 Preop, n=19 Postop)

VARIABLE	r^2	+AREA R^2	+SHAPE R^2
SLR (DEGREES)	.106	.140	.143
WLR (DEGREES)	.211	.214	.241
FORWARD FLEXION	.017	.077	.108
EXTENSION	.104	.107	.449
RIGHT FLEXION	.286	.340	.597
LEFT FLEXION	.239	.252	.646

Table 33 lists the effect of the canal cross section and shape on the improvement in extension. Canal cross section increased the variation explained in extension from 10% to 11%. However by adding the canal shape to the regression equation, the variation accounted for increased from 11% to 45%. This finding was approached significance ($p \leq .06$ level).

Table 33

Multiple Regression for the Amount of Variation in Postoperative Extension Explained by the Canal Cross Section and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
EXT PREOP	.119	.124	.220	.32
CROSS SECTION	-.021	.291	-.017	-.09
DELTOID	1.109	.388	.610	.48
TREFOIL	.717	.411	.395	.22
CONSTANT	2.236	1.167		
	$R^2=.449$	F=2.86	$p \leq .06$	

Table 34 reports the addition of canal shape to canal cross section in right side flexion. Canal cross section increased the variation explained from 29% to 34%, and addition of canal shape significantly further increased the variation explained to 60% ($p \leq .01$).

Table 34

Multiple Regression for the Amount of Variation in Postoperative Right Flexion Explained by the Canal Cross Section and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
R FLEX PREOP	.384	.149	.525	.54
CROSS SECTION	.335	.456	.140	-.01
DELTOID	1.071	.675	.316	.32
TREFOIL	1.840	.627	.543	.40
CONSTANT	1.095	1.870		
	$R^2=.597$	$F=5.18$	$p \leq .01$	

The variation in left flexion explained by the canal cross section and shape is listed in Table 35. The proportion of right flexion only increased by 1%, from 24% to 25% (Table 32) when the cross section was added, but the addition of canal shape significantly increased the variation accounted for to 65% ($p \leq .01$).

Table 35

Multiple Regression for the Amount of Variation in Postoperative Left Flexion Explained by the Canal Cross Section and Canal Shape
(n=20 Preop, n=19 Postop)

VARIABLE	B	SE B	BETA	r
L FLEX PREOP	.153	.105	.272	.49
CROSS-SECTION	-.128	.410	-.056	-.08
DELTOID	1.508	.594	.462	.29
TREFOIL	2.247	.590	.688	.54
CONSTANT	4.149	1.614		
	R^2=.646	F=6.38	$p \leq .01$	

Table 36 lists the point biserial correlation coefficients of the canal measurements with canal shapes. The trefoil shape and transverse diameter were highly associated (r=.68), and the triangular shape and the transverse diameter were highly negatively associated (r=-.61). There was a moderate association (r=.46) between the triangular shape and the sagittal diameter.

Table 36

Point Biserial Correlation Coefficients for Association Between the Canal Sizes and Shapes (n=20)

SPINAL CANAL	TRIANGULAR	DELTOID	TREFOIL
SAGITTAL	.46* ($p \leq .020$)	-.27 ($p \leq .121$)	-.24 ($p \leq .152$)
TRANSVERSE	-.61* ($p \leq .002$)	.01 ($p \leq .477$)	.68* ($p \leq .000$)
CROSS SECTION	-.08 ($p \leq .371$)	-.07 ($p \leq .383$)	.17 ($p \leq .242$)

*denotes $p \leq .01$

CHAPTER V

DISCUSSION

The purpose of the study was to examine the relationship between the spinal canal shape and dimensions and clinical findings in low lumbar discectomy patients. The canals were measured on the CT image monitor with an electronic pen. The canal was measured at the midpedicle of the vertebra above the level of the lesion for the sagittal and transverse diameters, and the cross-sectional area. The canal was also evaluated for shape at this midpedicular slice and classified as oval, triangular, trefoil or deltoid.

The clinical parameters which were measured preoperatively and postoperatively were pain at best, pain at worst, SLR, WLR, forward flexion, extension, right side flexion, and left side flexion.

Canal diameters have been measured on a CT scanner by Ullrich et al. (1980). Their average AP diameter at L4 was 16 mm, and at L5 was 17 mm which compared closely to the 17 mm (SD=2.0) mean of both L4 and L5 levels found in this study (Table 7). Their average transverse diameter was 24 mm at L4 and 26 mm at L5, which was less than the 29 mm (SD=4.0) found in the present study. However, subject number 20 had a 40 mm wide canal which likely skewed the data

(Appendix G). Their average cross sections of 2.4 cm² at L4 and 2.9 cm² at L5 were smaller than the mean of 3.43 cm² (SD=.62) found in this study. The fact that their cross section was smaller than that reported in this study could be due to their smaller matrix size (256 x 256), and larger pixel size. Also, they did not tilt the gantry, rather measured sagittal reconstructions of patients having scans for abdominal investigation. As well, the patients were not positioned on the scanning table to flatten the lumbar lordosis as was done in the present study, rather the legs were extended.

The classification of the correlations for association of one variable with another is listed in Table 37.

Table 37

Descriptive Categories for Correlation Coefficients (r) and Correlations Squared (r²)

Correlations (r)		Correlations Squared (r²)
0 to .29	LOW	0 to .08
.30 to .49	MODERATE	.09 to .24
.50 to .69	HIGH	.25 to .48
.70 to 1.00	VERY HIGH	.49 to 1.00

The correlation coefficients of the canal cross section with the sagittal and transverse diameters (Table 11) have not been reported previously in the literature. The cross section and sagittal measurements had a strong association (r=.64) between them (p≤.001). As the cross section increased, so did the sagittal diameter. The cross-sectional and transverse measures also had a high association (r=.57, p≤.004). The association between the transverse and sagittal diameter was low and negative (r=-.16, p≤.245). As the transverse canal increased, the sagittal diameter decreased. Baddeley (1976) also found no correlation between the two diameters and reported them to vary independently. These findings are in contrast to the correlation of .35 reported by Clark et al. (1985) in their study of 87 prehistoric American Indian skeletons. Their sample size was, however much larger.

The midsagittal diameter has been stated to be the most significant clinically, and to suffer from stenosis twice as often as the transverse diameter (Clark 1985, Eisenstein 1977, Porter 1980). Ehni (1969) reported that the interpedicular measures remained normal and gave no clue as to the existence of a small canal in the lumbar region. Winston et al. (1984) found the sagittal diameter to be significantly smaller in patients operated on for lumbar radiculopathy while the transverse diameters were not. Verbeist reported the midsagittal diameters to be the most reliable measurements and the most amenable to a comparative study (1977).

If the sagittal canal is the most clinically significant, it would follow that the cross section, with its close association with the AP diameter would also be highly significant.

A. Pain at Best, Pain at Worst

No significant relationship was found between pain at best or worst and canal size (Table 12).

One reason for the pain scales having such low correlations with the canal diameters could be that the patients tended not to use the full pain scale, although they could choose from six levels of pain (Appendix B). Except for the postoperative pain at worst where there was slightly more variation, patients tended to use the ends of the scale, that is 'mild' or 'discomforting' at best, and 'horrible' or 'excruciating' at worst (Appendix G). The lack of variation could likely have caused the low correlations.

The patients which were included in the study were operative candidates due to their severe signs and symptoms. It is likely that had less involved patients been included in the study, the scale would have been used more fully. Rather than the pain scale itself being the problem, patient selection was likely responsible.

There was little difference between the means of the three canal shape groups in pain (Table 16). Shape explained only a minimal amount of the variance between the groups in all pain variables. The differences between the three group means were not significant.

The proportion of variation in pain explained by the preoperative values (Table 20), canal size and shape on improvement in the pain variables, were also negligible. The pain values were included in the regression equation were not reported due to their being so small and insignificant. These findings were again likely due to the limited range on the pain scale which was utilized.

B. Straight Leg Raise, Well Leg Raise

A nonsignificant association was found between the canal sizes and the range in degrees of the SLR or WLR preoperatively and postoperatively (Table 13). Point biserial correlations were computed to determine the relationship between the positive and negative tests, and canal sizes (Table 14). As the sagittal canal diameter increased, patients tended to have positive SLR tests preoperatively ($r=.40$, $p\leq.04$). However, the SLR test was positive preoperatively in all but one patient so that these findings are likely spurious and therefore not meaningful. As the transverse canal diameter increased, patients tended to have negative WLR tests postoperatively ($r=-.31$, $p\leq.10$). The association was not strong and only approached significance.

The one-way analysis of variance (Table 17) was calculated in order to compare the means of the clinical variables for the three canal shape groups. There were neither large nor consistent differences between the group means in the SLR or WLR tests, and shape explained only 1% of the variability between the SLR groups preoperatively, and 0.1% postoperatively. For WLR, shape only explained 5% of this variability preoperatively and postoperatively.

Multiple regression was then calculated in order to determine the improvement in SLR and WLR explained by the canal sizes and shapes. Eleven percent (Table 20) of the variation in the SLR was explained by knowing the preoperative value (r=.33). Adding the effect of the sagittal canal increased the variation in SLR by only 1%, to 12% (Table 21). The sagittal canal did not explain the improvement in the SLR. The addition of shape to the regression equation did not increase the variation accounted for in SLR. As well, adding the transverse canal (Table 26) only increased the variation accounted for by 1%, from 11% to 12%. Shape increased this only to 14%.

Next, the effect of the cross-sectional canal area on SLR improvement was examined. Adding the cross section increased the proportion of variation explained from 11% to 14% and the addition of shape did not further increase this value (Table 32). Canal size and shape explained little improvement in SLR.

Regression was then calculated on the WLR. The preoperative value had a moderate positive correlation (r=.46) with the postoperative value and accounted for 21%

of the variance in the postoperative WLR (Table 20).

The sagittal canal diameter increased the proportion of variation explained to 26% (Table 21), and adding the shape further increased the variation explained to 34% ($p \leq .19$).

Adding the transverse diameter (Table 26) had a negligible effect on the variance which increased 1% from 21% to 22%. Adding the shape had an effect of having 30% of the variance accounted for ($p \leq .26$).

The cross-sectional canal diameter (Table 32) did not explain any increase in variation in the WLR as the value remained at 21%. The addition of shape into the regression equation increased the proportion of variation explained to only 24% ($p \leq .39$).

Canal size and shape explained little improvement in either WLR or SLR. Due to this small influence on improvement in these variables, the regression tables were not examined in detail.

C. Forward Flexion

The mean preoperative value was 2.5 cm and postoperatively it had increased to 4.3 cm (Table 10). These values were lower than the norms established for this age group of 6.59 cm (average of male and female values) by Moll and Wright (1971) and attributable by the lumbar disc lesions in the patient sample.

Only small relationships were found between the AP, transverse or cross-sectional canal measurements and forward flexion (Table 15).

One-way analysis of variance indicated no statistically significant difference between the group means (Table 18). There was more variance within the groups than between the groups. Shape only accounted for 5% of the variance between the groups preoperatively and 4% postoperatively.

In using the regression equation to determine the proportion of variation in forward flexion explained by canal size and shape, the three outliers had an effect of reducing the correlation between preoperative and postoperative flexion by changing the relationship into a nonlinear one. Patient 14 had a decrease in flexion between the preoperative and postoperative score, and patients 8 and 20 both had no forward flexion preoperatively, and improved to 6 cm and 5.5 cm respectively (Appendix G). These outliers tended to reduce the linear relationship, and thus the correlation. The correlation between preoperative and postoperative forward flexion was negligible and (r=.13), but with the three outliers removed, the correlation increased markedly to r=.57, achieving the highest correlation between preoperative and postoperative values.

The regression (including the outliers) did not show any significant explanation of variation in forward flexion. Reassessing the patients at one year, should give a much better indication of the effects of canal sizes and shape on flexion, because their physical status should be more stabilized.

The question to be asked is whether 15% of all patients undergoing the present surgery will react like the three patients above, or whether the outliers would only have occurred in three patients given a larger sample. Only by testing more patients would this be clarified.

D. Extension

The mean extension value observed in the present study was 2.9 cm preoperatively, and 3.0 for the group postoperatively (Table 10). At L4-5, the postoperative mean was 2.2 cm, and at L5-S1: 3.3 cm. The mean reported for this age group by Moll and Wright (1971) was 3.41 cm (average of normal males and females). Extension remained close to the normal values both preoperatively and postoperatively. The exercise program which the patients performed included extension exercises (Appendix F).

Postoperatively, a significant difference was found between the L4-L5 patients (mean=2.2 cm) and the L5-S1 patients (mean=3.3 cm), with the later group having a larger ROM. Farfan (1973) reported 10° of extension to normally occur at L4-L5 and 6° at L5-S1. Removal of the L4-L5 disc may cause more limitation of extension at this level since normally, most of the movement would occur here. This level is possibly affected more by the surgery.

No significant relationship was found between the group preoperative extension and the canal diameters (Table 15). As the canal cross section increased the preoperative extension tended to decrease ($r=-.35$, $p\le.07$).

A marked difference occurred, however, when the groups were split at the two levels. At the L4-L5 level, there was a very high positive association between the sagittal canal diameter and postoperative extension ($r=.94$, $p\le.002$). A one SD change in the sagittal canal accounted for .94 SD increase in the postoperative extension. Most of the extension occurs at this level normally (Farfan 1973), so that possibly it is influenced the most by the sagittal canal diameter. The canal cross section was also very highly correlated ($r=.72$) with the postoperative extension. As the cross section increased by 1 SD, the postoperative extension increased by .72 SD ($p\le.05$). The transverse canal had no significant effect at this level. At the L5-S1 level, the transverse measurement had a moderate negative association (-.34) with the postoperative extension which approached significance at the .10 level ($p\le.13$). As the transverse canal increased by 1 SD, the extension decreased by .34 SD. The sagittal and cross-sectional canal measurements had no significant association with extension at the L5-S1 level.

The one-way analysis of variance (Table 18) for preoperative extension found the triangular group to have the least amount of extension (mean=2.36 cm) and the deltoid group to have the most (mean=3.45 cm). The trefoil group was in the middle (mean=3.15 cm). There was, however, still more variance within the groups than between them. Shape only explained 8% of the variance between the groups, which is an increase from the previous variables, but not considered to be practically meaningful.

There were significant differences between the means for the three canal shape groups in postoperative extension. There was now more variation between the groups than within. The observed F ratio (F=5.32) exceeded the critical F of 3.63 (p≤.02). Canal shape accounted for 40% of the variation between the groups in postoperative extension. The triangular and deltoid canals were found to be significantly different (p≤.05) with the Scheffé test (Table 19). Patients with deltoid shaped canals had the most postoperative extension (mean=3.60 cm) followed by the trefoil group (mean=3.25 cm) and lastly by the triangular group (mean=2.44 cm). There were only triangular canals at the L4-L5 level, so that analysis of variance could not be computed at this level. At the L5-S1 level, the analysis of variance (Table 18) showed the deltoid canals to have the most extension (mean=3.60 cm). The trefoil canals followed (mean=3.25 cm) and the triangular canals had the least postoperative extension (mean=2.91 cm). Shape accounted for 20% of the variance in postoperative extension at the L5-S1 level (p≤.49).

Multiple regression was then calculated. Ten percent (r=.32) of the variation in postoperative extension was explained by the preoperative value (Table 20). Every 1 SD increase in preoperative extension was associated with an increase in the postoperative value of .32 SD (p≤.09). The proportion of variation explained the increase of only 11% when the sagittal canal was added, but the addition of shape into the regression equation increased the variation explained to 48% (Table 21).

If the canal was deltoid, extension would improve by 2.13 cm (Table 23) controlling for extension preoperatively and the sagittal canal diameter. If the canal shape was trefoil the improvement would be 1.71 cm, and if it was triangle, it would only improve by .87 cm. Controlling for shape, if the sagittal canal diameter increased by 1 mm, extension would only improve by .07 cm. The correlation of the deltoid canal shape and the postoperative extension was .48 compared to the sagittal canal at -.18.

The deltoid canal shape had a large influence on postoperative extension, followed by the trefoil shape, the preoperative value, and lastly, by the sagittal canal which had a small effect ($p \leq .05$). Patients with deltoid canals had the most postoperative spinal extension (Table 19), and had the best improvement in spinal extension (Table 23).

The transverse canal increased the proportion of variation explained from 10% to 16%, but the addition of shape explained a large increase in the variation - 46% (Table 26).

Table 29 shows the effect of shape on improvement of extension as compared to the effect of the transverse canal. If the canal was deltoid, controlling for the extension preoperatively and the deltoid canal diameter, the predicted improvement in extension was 4.53 cm. If the canal was trefoil, this improvement was 4.30 cm, and if the canal was triangular: 3.28 cm. For one mm increase in the transverse canal diameter, postoperative extension would decrease by .04 cm controlling for the preoperative value and shape. The deltoid shape explained the most improvement in extension, followed by the trefoil shape, transverse canal, and lastly by the preoperative extension value. The correlation between the deltoid canal and the postoperative extension was .48, as compared with the transverse canal which was only .21. The deltoid canal shape had the greatest effect on improvement of postoperative extension.

The canal cross section increased the variation in extension by only 1%, from 10% to 11%. The addition of canal shape, however, explained 45% of the variation (Table 32). Table 33 reports the effect of canal shape on improvement in postoperative extension. Once again, the greatest effect on improvement was the deltoid canal shape. If the canal was deltoid in shape, controlling for the preoperative extension and the canal cross section, the amount of improvement in postoperative extension was 3.35 cm. If the canal was trefoil, the improvement was predicted to be 2.96 cm, and if the canal was triangular, the improvement was predicted to be 2.24. An increase in the canal cross-section of 1 cm^2 led to a minimal decrease in extension of .02 cm. The influence on improvement in extension in order of greatest to least was the deltoid canal shape, trefoil canal shape, the preoperative value and lastly the canal cross section, with a small negative effect. These effects approached significance ($p \leq .06$). The greatest improvement in postoperative extension could be predicted for patients with deltoid shaped canals.

E. Right Side Flexion

The mean right side flexion in this investigation was 4.3 cm preoperatively and 4.6 cm postoperatively (Table 10). Moll and Wright (1971) reported a mean of 5.06 cm for the 35 to 44 year olds (average of male and female values).

Table 15 shows that there was a moderate negative association between the right flexion preoperatively and the cross-sectional canal measurement ($r=-.39$, $p \leq .04$). As the cross section increased by 1 SD, right flexion decreased by .39 SD. Preoperatively, right flexion had a low negative association ($r=-.27$) with the sagittal canal which approached significance ($p \leq .12$) Right flexion postoperatively had a moderate positive association with the transverse canal diameter ($r=.40$, $p \leq .05$). As the transverse canal increased so did the right side flexion, but as the sagittal diameter increased, the right side flexion decreased. The transverse canal was positively associated with movements in the frontal plane, and the sagittal canal affected these movements negatively.

The analysis of variance for comparison of the canal shape means on right side flexion is listed in Table 18.

Preoperatively, the group means approached a significant difference ($p \leq .13$). The deltoid group had the largest ROM (mean=5.75 cm) followed by the trefoil group (mean=3.80 cm) and the triangular group had once again the smallest mean (mean=3.61 cm). Shape accounted for 20% of the variance between the groups. Postoperatively, a significant difference between the group means occurred ($p \leq .02$). The largest mean was found in the trefoil group (mean=5.60 cm), followed by the deltoid group (mean=5.40 cm), and lastly by the triangular group (mean=3.61 cm). Shape accounted for 40% of the variance between the groups.

The Scheffé test (Table 19) indicated the significant difference to occur between the triangular and trefoil groups ($p \leq .05$).

Multiple regression was then computed. The preoperative right flexion accounted for 29% of the variation in postoperative right flexion (Table 20). Adding the sagittal canal explained only an additional 1%, so that 30% of the variance in right flexion was accounted for (Table 21). The addition of shape to the regression equation of the sagittal canal accounted for an additional 30%, so that 60% of the variance was now accounted for.

Table 24 illustrates in more detail the effect of entering shape into the equation with the sagittal canal. The trefoil shape had the effect of improving the right flexion by 2.45 cm controlling for the preoperative value and the sagittal canal diameter. The deltoid shape had the effect of improving the value by 1.66 cm and having a triangular canal improved the right flexion by .29 cm. Increasing the sagittal canal by 1 mm would improve the right flexion by .11 cm controlling for shape and the preoperative value. The trefoil shape explained the most improvement in right flexion followed by the preoperative value, then the deltoid shape, and lastly by the sagittal diameter. The trefoil canal had a moderate positive association (r=.40) with postoperative right flexion and had the strongest association with the right flexion.

The transverse canal did influence improvement in right flexion (Table 26). The proportion of variation explained improved from the preoperative value of 29% to 53% by addition of the transverse value. Table 27 reports that for a 1 mm increase in the transverse canal diameter, the right flexion improved by .18 cm controlling for the preoperative value ($p \leq .01$). In the present study, the range of the transverse canal diameter was 13 mm (23 to 36 mm). If a patient's canal was 10 mm wider preoperatively, the right flexion would improve 1.8 cm controlling for the effect of the preoperative value. In contrast a patient with a canal which was 23 cm rather than 33 cm wide would only improve by .18 cm in right side flexion.

Adding shape into the regression equation with the transverse canal (Table 26) explained an additional 6% of the variation in right flexion, which increased from 53% to 59% ($p \leq .01$). Having a trefoil canal would give a patient

1.86 cm more right side flexion controlling for the transverse canal effect and the preoperative value (Table 30). Having a deltoid canal would improve the variable by 1.31 cm, and having a triangular canal lead to a .45 cm improvement. A 1 mm increase in the transverse canal would lead to a .07 cm increase in the right flexion controlling for canal shape and the preoperative value. The preoperative value explained the most improvement in right side flexion followed by the trefoil canal shape, the deltoid shape, and lastly by the transverse canal diameter ($p \leq .01$). What appeared to be a large effect of the transverse canal was in fact due to having a trefoil canal shape as can be seen by examining the Beta values (Table 30).

Patients with trefoil and deltoid canal shapes had the most right side flexion preoperatively and postoperatively. Variation in right side flexion was explained largely by the trefoil canal shape.

F. Left Side Flexion

The preoperative value of 4.7 cm and the postoperative value of 5.4 cm (Table 10), compare with the established normal value of 5.15 cm (Moll and Wright 1971) for this age group (average of male and female values).

Table 15 shows that there was a moderate negative association between the left flexion preoperatively and the sagittal canal ($r=-.34$) which approached significance ($p \leq .07$). The canal cross section also had a moderate negative relationship with the preoperative left flexion ($r=-.36$, $p\leq.06$).

Postoperatively, left flexion was also moderately negatively associated with the sagittal canal ($r=-.38$, $p\leq.055$). The transverse diameter, however, had a moderate positive association with the left side flexion postoperatively ($r=.42$, $p\leq.04$). The movements in a frontal plane tended to be positively associated with the transverse diameters and negatively associated with the sagittal and cross-sectional diameters.

Weisz and Lee (1983) have discussed the concept of neural tissue mobility. Spinal movements induce a traction effect on neural tissue. The authors have reported a "spinal reserve capacity" which is the space between the bony wall and the dural sac. This functional space, they reported, is necessary for tension free movements of the neural contents of the spine. They suggested that decreased spinal mobility may be related to decreased neural mobility in a lumbar canal with a reduced reserve capacity. Possibly, intracanal space in one direction allows increased movement in the same plane, supporting the findings of the present study.

Table 18 reports the differences between the group means for canal shape. Preoperative left flexion had the largest values in the deltoid group (mean=6.08 cm), followed by the trefoil group (mean=5.00 cm). The triangular group had the smallest values (mean=3.67 cm). Shape accounted for 16% of the variance between the groups, however significance was not attained (p≤.23).

Postoperatively, the trefoil group had the largest mean (mean=6.70 cm) followed by the deltoid group (mean=6.10 cm) The smallest mean was again found within the triangular group (mean=4.28 cm). Because there was more variation between the groups than within them, the F ratio was highly significant (p≤.001). Fifty seven percent of the variance in postoperative left side flexion could be attributed to the canal shapes.

The Scheffé test (Table 19) indicated significant differences between the triangular and deltoid canal shapes, and between the triangular and trefoil canals. The patients with trefoil shaped canals had the best results in postoperative left flexion, closely followed by the deltoid shaped canals, while patients with triangular shaped canals had the worst results in postoperative left flexion.

The fact that the deltoid and trefoil canals had better outcomes than the triangular canals contradicts the present research hypothesis. In postoperative extension, preoperative right and left side flexion, the patients with deltoid shaped canals had larger ranges of motion. In the postoperative left and right flexion, patients with trefoil shaped canals had the largest ranges of motion. In all clinical variables demonstrating significant differences between the means, the triangular group had the smallest ranges of motion.

Some authors feel the trefoil shape is a normal anatomical configuration, while others feel that it is pathological: Porter et al. (1978b, 1980) wrote that many of the patients with disc symptoms have canals of the trefoil shape. Postacchini (1983) has stated that the trefoil canal is a normal developmental variation; is estimated to occur in 10-20% of the normal adult population at the L5 level; and, is of no consequence in the absense of compressive agents.

A trefoil canal should not be confused with the trefoil appearance produced by facet hypertrophy which can can cause stenosis of the central canal and lateral recess (Helms and Vogler 1982). Eisenstein (1977) examined lumbar canals for shapes and found that 92% of the trefoil canals occurred at L5. He described these findings as a normal variation of the developmental anatomy. This investigation would support these findings as all occurrences of trefoil canals occurred at L5. Even though the canal may be a trefoil shape, it may still be very large. The canals were not evaluated for shape at the facet joints, but rather at the midpedicles.

Multiple regression was performed. Preoperative left flexion explained 24% of the variation in the the postoperative value (Table 20). The association between the two was high (r=.49). The sagittal canal explained an additional 5% of the variance in the left side flexion increasing the value to 29% (Table 21).

For each 1 mm increase in the sagittal diameter, the left flexion decreased by .15 cm controlling for the preoperative value (Table 22). The sagittal canal had a moderate negative association with the postoperative value (r=-.38). This small value was overidden by the preoperative value and canal shape as it amounted to half of the positive effect of the preoperative value (as listed under Beta).

The canal shape increased the variance accounted for from 29% to 64% (Table 21). If the patient had a trefoil shaped canal (Table 25), the amount of improvement in left flexion controlling for the preoperative value and the sagittal canal diameter was 5.53 cm. If the canal was deltoid, the improvement was 4.81 cm, and if it was triangular, the improvement was 3.29 cm (p≤.01). The trefoil and deltoid shape had the strongest effects on improvement in left flexion followed by the preoperative value. The sagittal canal had the least effect on the outcome.

The transverse canal (Table 26), explained an increase of 19% of the variation in the left flexion, increasing the variation explained to 43% from 24%. Table 28 illustrates that for a 1 mm increase in the transverse canal diameter, a patient will have an increase of .15 cm in left side flexion, controlling for the effect of the preoperative value (p≤.01).

The addition of shape to the equation (Table 26) increased the variance accounted for to 65% from 43%, amounting to a 22% increase (p≤.01). By adding the shape and examining the Beta values (Table 31), it could be seen that the transverse diameter did not have a large effect on improvement in left flexion, rather, having a trefoil canal accounted for the greatest improvement. Controlling for the preoperative value and the transverse diameter, if a patient had a trefoil canal, the improvement in left flexion would be 7.80 cm, and with a deltoid shaped canal, 6.87 cm, and with a triangular canal, 5.17 cm. The trefoil shape explained the most variation in left flexion followed by the deltoid shape and then the preoperative value ($p \leq .01$). What appeared to be the transverse canal measurement effect was really attributable to the trefoil shape.

Canal cross section had a very minor effect on the left flexion. The variation explained was increased by 1%, from the preoperative effect of 24% to 25%. The addition of shape increased the variance accounted for to 65%, an increase of 30% (Table 32).

If the patient had a trefoil shaped canal (Table 35), controlling for the preoperative value, and the canal cross section, the improvement in left flexion would be predicted to be 6.40 cm, and with a deltoid canal, 5.66 cm, and a triangular canal, 4.15 cm. A 1 cm^2 increase in the cross section was associated with a decrease in left flexion of .13 cm controlling for the preoperative value and canal shape. While the canal cross section did not affect change, canal shape caused a marked improvement. Having a trefoil canal, followed by a deltoid canal had the largest postive effect on left flexion.

The values from the regression equation could be used to predict a patient's outcome based on preoperative examinations. The regression equation which would be used would be the following:

$$y' = a + b1x1 + b2x2 + b3x3 + b4x4$$

where y' = the predicted postsurgical left flexion value
a = the constant, the triangular canal shape
b = the increase in y' for a unit increase in x
$x1$ = the independent variable, left flexion before
$x2$ = the independent variable, deltoid shape
$x3$ = the independent variable, sagittal diameter
$x4$ = the independent variable, trefoil shape

For example, using the data in Table 35, if a patient had a triangular canal, left flexion before surgery was 4 cm, and the canal cross section was 3.43 cm^2:

$$y'=4.15 + (.15)(4) + (1.51)(0) + (-.128)(3.43) + (2.25)(0)$$

the postsurgical left flexion could be predicted to be:

$$= 4.15 + .6 + 0 + (-.44) + 0$$

$$= 4.31 \text{ cm}$$

If the same patient had a trefoil canal, the postsurgical left flexion would be higher:

$$y'= 4.15 + (.15)(4) + (1.51)(0) + (-.128)(3.43) + (2.25)$$

$$= 6.56 \text{ cm}$$

In conclusion, the cross-sectional and sagittal canal measurements tended to affect the clinical variables similarly while the transverse diameter tended to affect the variables in the opposite way. There was a significant difference in the canal shape group means in postoperative extension, and right and left side flexion ROM measures. Patients with the deltoid and trefoil canals had the greatest ROM while those with the triangular canals had the least.

Since the relationships which appeared to be due to canal diameter measurements, turned out in fact to be due to canal shape, correlation coefficients were calculated in order to determine the relationships between canal sizes and shapes (Table 36). The sagittal canal had a moderate positive association with the triangular canal shape ($r=.46$, $p\leq.020$) as both are larger in the sagittal plane. The transverse diameter had a high negative association with the triangular shape ($r=-.61$, $p\leq.002$). As the transverse diameter increased, patients tended not to have triangular canals. The transverse canal had a high association with the trefoil shape ($r=.68$, $p\leq.00$). As the transverse diameters increased, the canals tended to become trefoil in shape. The canal cross section had slight or low associations with all of the canal shapes.

The cross-sectional canal size, a measurement only presently possible with CT scanning, had the most disappointing relationships with the clinical variables. Looking at the sagittal and the transverse diameters, it could be stated that they tended to be positively associated with the shapes that were largest in the plane which they were in. It was the canal shape and not the size which accounted for the most improvement in spinal ROM following low lumbar discectomy. It was not the cross section but the way which the cross section was distributed which affected spinal ROM.

Canal shape cannot be demonstrated by radiographs or myelograms (Weir and Deleo 1981). Surin (1982) wrote that with the advance of computed tomography, there is growing evidence that the shape of the canal is as important as the sagittal transverse diameter. The findings of this investigation are in agreement. Further studies on the shape and dimensions are warranted.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The purpose of the present study was to examine the relationship between spinal canal morphometry and clinical findings in patients having undergone low lumbar discectomy.

The spinal canals of patients were measured on a CT image console with an electronic pen. Measurements of the sagittal and transverse diameters, and the cross-sectional area were completed using a standardized method at the midpedicular level of the vertebra above the affected disc. Canal shape was classified as oval, triangular, deltoid or trefoil in an objective and standardized manner.

A sample of 20 patients, aged 24 to 56 years was studied. In accordance with the inclusion criteria, all patients had disc lesions at the L4-L5 or L5-S1 level which were viewed at surgery. The patients were examined preoperatively and at six weeks postoperatively for pain its best, pain at its worst, straight leg raise, well leg raise, forward flexion, extension, right side flexion and left side flexion. All methods utilized for examination had been examined for validity and reliability.

Student t tests and Fischer exact tests were calculated in order to determine whether the two vertebral levels could be grouped together for statistical analysis on all dependent variables. Only postoperative extension was observed to be significantly different ($p \leq .05$) at the two levels. This variable, was therefore analyzed separately at the two levels where possible.

The frequencies, means and ranges of the criterion measures and canal measurements were described and compared to those reported in the available published literature. Pearson product moment correlation coefficients were calculated in order to determine the association between the canal measurements, with the clinical variables, and between the clinical variables before and after surgery. Point biserial correlations were used to determine the relationship between dichotomous and continuous data. One-way analysis of variance was calculated to analyze whether the clinical variables differed with different canal shapes and, in the event of a statistically significant F ratio, Scheffé tests determined which of the group means were significantly different from each other. Multiple regression was computed in order to determine the proportion of variation in the postoperative values explained by the preoperative values, canal shapes and canal sizes. First the canal sizes were added to the equation, followed by the addition of the canal shapes. This method of computation served to determine the amount of improvement in the clinical variables explained by the preoperative value, canal sizes and shapes.

Conclusions

With the data available from the present study, the following conclusions were made:

1. The cross-sectional and the sagittal canal measurements were significantly highly related ($r=.64$, $p\leq.001$). As one increased by one SD, the other increased by .64 SD. Thus, the two measurements tended to affect the clinical parameters in the same way.
2. The transverse and the sagittal canal measurements had a low negative association between them ($r=-.16$, $p\leq.245$). As one increased by one SD, the other decreased by .16 SD.
3. The transverse and the cross-sectional canal measurements were significantly highly associated ($r=.57$, $p\leq.004$). As one increased by one SD, the other increased by .57 SD.
4. Age, sex, canal measures and clinical parameters had no significant difference between them at the two vertebral levels, except postoperative extension in which the mean was 2.2 cm at L4-L5 and 3.3 cm at L5-S1 ($p\leq.05$). The two groups were therefore analyzed separately where possible.
5. The sagittal canal measurement and the postoperative extension (at the L4-L5 level) had a significant very high positive association between them ($r=.94$, $p\leq.002$). As the sagittal canal increased by one SD, the postoperative extension increased by .94 SD. After

further analysis, it was found that this relationship appeared to be more attributable to the deltoid canal shape (or less so by the trefoil shape) than to sagittal diameter.

6. The sagittal canal and the preoperative left flexion had a moderate negative association between them (r=-.34, p≤.07). As the sagittal canal increased by one SD, the preoperative left flexion decreased by .34 SD.
7. The sagittal canal and the postoperative left flexion had a moderate negative association between them (r=-.38, p≤.055). As the sagittal canal increased by one SD, the postoperative left flexion decreased by .38 SD.
8. The sagittal canal measurement and the preoperative SLR (sign) had a positive moderate significant association between them (r=.40, p≤.04). As the sagittal canal measurement increased in size, the SLR tended to become positive. However, as all but one of the SLR tests were positive preoperatively, this finding was likely a spurious relationship.
9. The canal cross section and the postoperative extension had a significant high association between them (r=.72, p≤.05). As the canal cross section increased by one SD, the postoperative extension increased by .72 SD. After further analysis, it was found that this relationship appeared to be more attributable to the deltoid canal shape (or less so by the trefoil shape) than to the

canal cross section.

10. The cross-sectional canal measurement and the preoperative left flexion had a moderate negative association between them (r=-.36, p≤.061). As the cross section increased by one SD, the preoperative left flexion decreased by .36 SD.
11. The cross-sectional canal and the preoperative extension had a moderate negative association between them (r=-.35, p≤.067). As the cross section increased by one SD, the preoperative extension decreased by .35 SD.
12. The canal cross section and the preoperative right flexion had a significant moderate negative association between them (r=-.39, p≤.044). As one increased by one SD, the other decreased by .39 SD. After further analysis, when the effect of shape was taken into account, it was found that this relationship did not affect right flexion postoperatively in a negative way.
13. The transverse canal and the postoperative right flexion measurements had a significant moderate association between them (r=.40, p≤.05). As the transverse canal increased by one SD, the postoperative right flexion increased by .40 SD. After further analysis, it was found that this relationship appeared to be more attributable to the trefoil canal shape (or less so by the deltoid shape) than the transverse diameter.

14. The transverse canal and postoperative left side flexion measurements had a significant moderate association between them (r=.42, p≤.04). As the transverse canal increased by one SD, the postoperative left side flexion increased by .42 SD. After further analysis, it was found that this relationship appeared to be more attributable to the trefoil canal shape (or less so by the deltoid shape) than the transverse diameter.
15. The transverse canal measurement and postoperative WLR (sign) had a low negative association between them (r=-.31, p≤.10). As the transverse canal increased in size, the WLR tended to become negative.
16. The spinal canal shapes significantly influenced patients values in postoperative right and left flexion, and extension. In postoperative extension the patients with deltoid canals had the highest ranges of motion. In the postoperative right and left flexion group, the patients with the trefoil shapes had the highest values.
17. In all ROM parameters with significant differences between the canal shape groups, the patients with the triangular canals had the worst results. This finding also applied in all cases which failed to reach statistical significance except in preoperative forward flexion.
18. Patients with deltoid canals had the most improvement

in extension, and those with trefoil canals had the most improvement in right and left flexion ($p \le .05$).

19. When canal shapes and sizes were evaluated for their respective influences on spinal range of motion, it was shape, and not size, which had the largest influence on patient improvement. Patients with trefoil and deltoid shaped canals had the best results in spinal range of motion following lumbar discectomy. Patients with triangular shaped canals had the poorest spinal ROM following low lumbar discectomy.

20. The results suggest that ROM is affected by that spinal canal diameter measurement which is largest in the same plane. Movements in a frontal plane were positively associated with a large transverse diameter and the especially the trefoil shape, and movements in an sagittal plane tended to be positively associated with a large AP diameter and the deltoid shape. The concept of the spinal canal reserve capacity may be associated with this finding. A reserve space may be necessary for tension free movements of the neural contents of the spine.

21. The relationship of canal shapes and sizes were analyzed and the sagittal canal was found to have a moderate positive association ($r=.46$, $p \le .02$) with the triangular canals. The transverse canal diameters had a high negative association ($r=-.61$, $p \le .002$) with the triangular canals and a very high positive association

(r=.68, p≤.00) with the trefoil canals. These findings support conclusion 20 above. Canal cross-section had low relationships with all canal shapes.

Recommendations

The major recommendations which can be made from the current study are as follows:

1. Patients who are treated conservatively should be evaluated to see whether their response to treatment can be explained by different canal shapes or sizes.
2. Subjects without low back pain should be evaluated in order to establish canal dimension norms in a standardized method using a newer generation CT scanner.
3. A larger number of subjects should be analyzed to assure that this investigation's results represent a larger patient population and can be generalized to lumbar disc patients as a whole with more certainty.
4. Patients should be reevaluated at one year postsurgically when a more definitive clinical outcome can be established. At six weeks postoperatively, it is doubtful that patients have regained their full spinal ROM.
5. Lateral recesses and intervertebral foramen sizes should be measured in order to establish whether their sizes have any clinical implications.
6. The reserve space within the canal between bony wall

and dura should be measured and correlated with the clinical variables.

7. Analysis of the flexion variable should be conducted without the extreme patients to examine whether 15% of patients, indeed, respond as did the three outliers in this study, or if given a larger sample, the deviant responses would have less of an impact.
8. A different pain scale which may be more sensitive for the type of patient included in this study may show more significant results with the pain variables.
9. The facet joint orientation should be examined to evaluate its influence on ROM.
10. The side of the sciatica should be correlated with the ROM variables.
11. The data should be analyzed using a breakdown for the patients' age to determine what effect age had on the clinical variables.
12. The data should be broken for sex to analyze whether males or females respond differently.
13. The degree of disc displacement should be correlated with the canal sizes, shapes and clinical variables.

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Worker's Compensation Board, Personal Communication, June 7, 1983.

APPENDIX A

Discharge Instruction Sheet

APPENDIX A

Discharge Instruction Sheet for Lumbar Discetomy Patients of Doctors Greenhill and Petruk:

1. Walking often and for short distances is encouraged. Let pain be your guide.
2. You should not sit for long periods of time. By your second or third day post-op, you can sit for 5-10 minutes at a time. This can be increased slowly. Let pain be your guide.
3. Do not lift heavy objects! Ask for help.
4. If you must reach for something low down, do so by bending at the knees and holding the back erect. Do not bend over at the waist!
5. Do not take any other treatment for your back (physiotherapy, chiropractic, medications, etc.) other than what your doctor prescribes.
6. Do not return to work until you have been examined by your doctor at 6 weeks.
7. A 6 week reexamination appointment at your Doctor's office will be arranged for you prior to your discharge by S. Kushner.

APPENDIX B

Present Pain Intensity Scale

APPENDIX B

Present Pain Intensity Scale

0 = NO PAIN

1 = MILD PAIN

2 = DISCOMFORTING

3 = DISTRESSING

4 = HORRIBLE

5 = EXCRUCIATING

APPENDIX C

Informed Consent For Investigative Study

APPENDIX C

INFORMED CONSENT FOR INVESTIGATIVE STUDY

Clinical Results and Spinal Canal Diameters in Disectomy Patients for Study of Dr. Greenhill, Dr. Petruk and S.Kushner

Outline of Procedures (Retained by subjects)

Research has found that different people have different sizes of their spinal canals. It is thought that the size of the spinal canal may affect the results that patients have following surgery for removal of the disc.

The study in which you are being asked to participate, involves measurement of your spinal canal on your CT scan (which your Dr. has requested) and drawing a relationship between it and the clinical findings before and after surgery. No extra tests or changes will be necessary for this study.

A one hour examination will be performed by the physiotherapist both before your surgery, in your hospital room, and six weeks after your surgery, at your surgeon's clinic. The tests will be those normally completed by your doctor or physiotherapist and include measurement of the movement in the spine, legs, muscle testing, and filling out a questionnaire. Your participation in the study will help physicians and physiotherapists improve the quality of care for patients undergoing spinal surgery in Canada. Participating in the study would not present any additional risks beyond those normally present with spinal surgery and a CT scan.

No records or photographs which will permit your identification will be made public without your written consent to do so. You will have the right to withdraw from participation in the study at any time. You are requested to read the enclosed instruction sheet very carefully.

In the event that questions arise concerning the study, please feel free to contact your physician or Shirley Kushner at 432-2068

INFORMED CONSENT FOR INVESTIGATIVE STUDY

Clinical Results and Spinal Canal Diameters in Discectomy Patients for Study of Dr. Greenhill, Dr. Petruk and S. Kushner

I,................................ do hereby agree to participate in the study entitled "Clinical Results and Spinal Canal Diameters in Discectomy Patients" to be conducted by Dr. Greenhill, Dr. Petruk, and Shirley Kushner. The nature of this study has been explained to me and I understand that I will not be subjected to any more risks from the study than the usual ones of spinal surgery or a CT scan. I have been advised that I may withdraw from participation at any time.

....	....
(Subject's Signature)	(Date)
....	....
(Address)	(Phone)

I was a witness during the explanation referred to above and to the signature

....	....
(Witness's Signature)	(Date)

APPENDIX D

Data Acquisition Form

The following collection sheet was used to
collect data for the overall study of which
the present study was a small part

APPENDIX D

Preop Examination Sheet for Discectomy Study Patients

Name:______________________RAH ID Number:__________

Date Preop Exam:______________Age:_______Birthdate:_____

Sex:_______Height:__________________Weight:__________

Address:____

____

Phone:____

Occupation:____________________Self Employed:_______

Time Off Work:_____________________________________

______________________________WCB:(yes or no)_______

Past Working History:_______________________________

____

Physical Activities at Leisure:_______________________

____

____

Other Hobbies:_____________________________________

____

Litigation Pending:_________________________________

HISTORY OF CURRENT EPISODE:

Onset:(Activity and Date)___________________________

____

____

____

____

____

____

Leg pain:(Onset and Date--if different from above)

Back pain:(Onset and Date--if different from above)

Present leg pain:(burning,sharp,throbbing,shooting,aching)

Present back pain:(burning,sharp,throbbing,shooting,aching)

Which is worse?

PRESENT PAIN INTENSITY:

0 No Pain, 1 Mild, 2 Discomforting, 3 Distressing,

4 Horrible, 5 Excruciating

Choose the word which best describes your pain right now:

At its best At its worst

Choose the best word: 1 Occasional, 2 Periodic, 3 Constant

Qualify above with amount per year:

Choose the best word: 1 Decreasing, 2 Static, 3 Increasing

What aggravates and what eases the pain?

Leg pain:*Aggravates--*

Eases--

Back pain:*Aggravates--*

*Eases--*______________________________

____

Night pain:(present or absent)______________________________

If present, describe:______________________________

Pain on rising in a.m.:______________________________

If present, describe:______________________________

Pain on Coughing?_______Sneezing?_______Deep Breath?_______

Pain on Walking?_______Twisting?_______Sitting?_______

If yes, is there a difference in pain if you
sit in an upright hard chair, or a soft arm chair?__________

____

Current Medications:______________________________

____

Do they provide relief?______________________________

How often?______________________________

DISABILITY:

0 Excellent-completely free from all back and leg pain. Can work and do all recreational activities without discomfort. Patient is symptom free with unrestricted activity.

1 Good-can perform all normal activities, but may occaisonally after heavy work have recurrent leg or back pain. Minor intermittent discomfort which does not interfere with normal activities. Patient can live and work normally and comfortably.

2 Fair-patient has had to reduce previous activities because of persistence of some pain

symptoms. Persisting back pain and/or sciatica interferes with the capacity to engage in normal activities. Patient has had to reduce activity.

3 Poor-the patient is frankly disabled. Patient has had to abstain from engaging in most normal activities.(Surin 1982, McCullough 1977)

ASSOCIATED MEDICAL ILLNESS:____________________

____

____

____

PAST MEDICAL AND SURGICAL HISTORY:________________

____

____

____

PREVIOUS LOW BACK PAIN AND ASSOCIATED PROBLEMS:________

____

____

____

____

____

PAST TREATMENT AND RESULTS:

Medications________________________________

____

Physiotherapy______________________________

____

Chiropractic_______________________________

____

Bed rest

BOWEL OR BLADDER DYSFUNCTION:

SEXUAL DYSFUNCTION:

If yes, due to pain or neurogenic reasons:

SLR:	Range	MHR	DF	Limitation & Location
Right				
Left				

WELL LEG RAISE:

REVERSE SLR:

REFLEXES:(absent, diminished, normal, exaggerated)

	Knee Jerk	Ankle Jerk	Med. Ham. Jerk
Right			
Left			

SPINAL ROM: Elicits pain:

Forward Flexion:

Right Side Flexion:

Left Side Flexion:

Extension

SUBJECTIVE COMPLAINTS OF WEAKNESS:

SUBJECTIVE COMPLAINTS OF WASTING:

VISIBLE MUSCLE WASTING:

MUSCLE TESTING:	Right	Left
Hip Flexors(L2-3)		
Quadriceps(L4)		
Dorsiflexors(L4-5)		
Extensor Hallucis Longus(L5)		
Plantarflexors(L5,S1-2)		
Hamstrings(S1-2)		

SUBJECTIVE COMPLAINTS OF NUMBNESS:

DERMATOMES:(specify R or L)

	pain	numbness	parasthesia
Buttock			
Saddle area			
Thigh			
--medial			
--lateral			
--anterior			
--posterior			
Leg			
--medial			
--lateral			
--anterior			
--posterior			
Foot			
--medial			
--lateral			
--dorsum			
--sole			
-full extremity			

Additional Comments:

PALPATION:	Tenderness	Spasm Elicited
L1		
L2		
L3		
L4		
L5		

POSTURE & POSTURAL SPASM:

____

____

____

ADDITIONAL COMMENTS:

____

____

____

____

____

____

____

____

Postop Examination Sheet for Discectomy Study Patients

Name:________________________________RAH ID Number:_________

Date of Surgery:____________Date Post-op Exam:______________

Has patient returned to work?________________________________

If yes, Date of Return to Work:______________________________

Type of activities at work:__________________________________

____

____

Present leg pain:(burning,sharp,throbbing,shooting,aching)

____

____

Present back pain:(burning,sharp,throbbing,shooting,aching)

____

____

Which is worse?____

PRESENT PAIN INTENSITY:

0 No Pain, 1 Mild, 2 Discomforting, 3 Distressing,

4 Horrible, 5 Excruciating

Choose the word which best describes your pain right now:

At its best__________________________At its worst_____________

Choose the best word: 1 Occasional, 2 Periodic, 3 Constant

Qualify above with amount per year:__________________________

____

Choose the best word: 1 Decreasing, 2 Static, 3 Increasing

What aggravates and what eases the pain?

Leg pain:*Aggravates--*_______________________________________

____

*Eases--*____

____

Back pain:*Aggravates--*______________________________

____

*Eases--*____

____

Night pain:(present or absent)_______________________

If present, describe:____________________________

Pain on rising in a.m.:___________________________

If present, describe:____________________________

Pain on Coughing?_______Sneezing?_______Deep Breath?_______

Pain on Walking?_______Twisting?_______Sitting?_________

If yes, is there a difference in pain if you
sit in an upright hard chair, or a soft arm chair?__________

____

Current Medications:_____________________________

____

Do they provide relief?___________________________

How often?______________________________________

____

DISABILITY:

0 Excellent-completely free from all back and leg pain. Can work and do all recreational activities without discomfort. Patient is symptom free with unrestricted activity.

1 Good-can perform all normal activities, but may occaisonally after heavy work have recurrent

leg or back pain. Minor intermittent discomfort which does not interfere with normal activities.
Patient can live and work normally and comfortably.

2 Fair-patient has had to reduce previous activities because of persistence of some pain symptoms. Persisting back pain and/or sciatica interferes with the capacity to engage in normal activities. Patient has had to reduce activity.

3 Poor-the patient is frankly disabled.
Patient has had to abstain from engaging in most normal activities.(Surin 1982, McCullough 1977)

BLADDER OR BOWEL DYSFUNCTION:______________________________

____

____

SEXUAL DYSFUNCTION:____

If yes, due to pain or neurogenic reasons:__________________

____

SLR:	Range	MHR	DF	Limitation & Location
Right				
Left				

WELL LEG RAISE:____

REVERSE SLR: ____

____

REFLEXES:(absent, diminished, normal, exaggerated)

	Knee Jerk	Ankle Jerk	Med. Ham. Jerk
Right			
Left			

SPINAL ROM: Elicits pain:

Forward Flexion: ____

Right Side Flexion: ____

Left Side Flexion: ____

Extension ____

SUBJECTIVE COMPLAINTS OF WEAKNESS: ______________________________

____

____

SUBJECTIVE COMPLAINTS OF WASTING: ______________________________

____

____

VISIBLE MUSCLE WASTING: ______________________________________

____

____

MUSCLE TESTING:	Right	Left
Hip Flexors(L2-3)		
Quadriceps(L4)		
Dorsiflexors(L4-5)		
Extensor Hallucis Longus(L5)		
Plantarflexors(L5,S1-2)		
Hamstrings(S1-2)		

MEASUREMENT OF SUCCESS: Benefit of the treatment

1 Worse

2 No major change

3 Small, but important improvement

4 Great benefit but not complete

5 Very great benefit, nearly or 100% better

(Lehman 1983)

SUBJECTIVE COMPLAINTS OF NUMBNESS:

DERMATOMES: (specify R or L)

	pain	numbness	parasthesia
Buttock			
Saddle area			
Thigh --medial			
--lateral			
--anterior			
--posterior			
Leg --medial			
--lateral			
--anterior			
--posterior			
Foot --medial			
--lateral			
--dorsum			
--sole			
-full extremity			

Additional Comments:

PALPATION:	Tenderness	Spasm Elicited
L1		
L2		
L3		
L4		
L5		

POSTURE & POSTURAL SPASM:

ADDITIONAL COMMENTS:

Operative Report for Dr. Greenhill, Dr. Petruk and S.Kushner's Discectomy Study

FINDINGS AT SURGERY:

*Patient's Name:*____

*Date of Surgery:*__________________________*Surgeon:*_________

1. Classification of Disc:
    1 Normal
    2 Disc Protrusion With Bulging Annulus
    3 Subligamentous Disc Prolapse ____mm
    4 Disc Extrusion With Central Attachment____mm
    5 Sequestration Without Migration ____mm
    6 Sequestration With Migration ____mm
2. Classification of Root:
    1 Normal
    2 Atrophied
    3 Edematous
    4 Inflammed
    5 Edematous and Inflammed
3. Relationship of Root to Protrusion:______________________
____
4. Lateral Recess Stenosis:___________________________________
____
5. Root Entrapment in Foramina:_____________________________
____
6. Preop Diagnosis:____
7. Level(s) Explored:____
8. Postop Diagnosis:____

---

9. Procedure:

    1 Discectomy

    2 Discectomy and Partial Laminectomy(Laminotomy)

    3 Discectomy and Lateral Gutter Decompression

    4 Discectomy and Hemi-laminectomy

    5 Discectomy and Full Laminectomy

    6 Other____

10. Anatomical Variations:____________________________________

11. Additional Comments:____________________________________

APPENDIX E

CT Scan Protocal
and
Data Collection Sheet

The following collection sheet was used to collect data for the overall study of which the present study was a small part

APPENDIX E

CT SCAN PROTOCAL FOR DISCECTOMY STUDY OF DR. GREENHILL, DR. PETRUK & S. KUSHNER

Study Parameters:

WINDOW WIDTH: 1500 CU

WINDOW LEVEL: 275 CU

MAS: 518 *TIME:* 7 SEC.

ZOOM FACTOR: 4.5

CUTS: 4 mm slices; 3 mm apart,

at discs 4 mm slices; 2 mm apart

TWO ADDITIONAL CUTS: at both L4 and L5

1. midpedicle, at the upper lamina, full bony outline
2. superior pedicle, facet joints visualized

WITH GANTRY ANGLED FOR BOTH IF NECESSARY FOR ALIGNMENT PARALLEL TO THE SUPERIOR END PLATE

USE SACRAL AND KNEE PADS TO DECREASE LORDOSIS

THIGHS AND LEGS ARE IMMOBILIZED WITH STRAPS

Patient Name________________________________Age________

Surgeon____________________________________Race________

Date of Scan:_______________________________Sex________

MEASUREMENT:

AT MIDPEDICLE--

1. AP *L4*______________________________*L5*__________
2. TRANSVERSE *L4*_______________________*L5*__________
3. CROSS-SECTIONAL AREA *L4*______________*L5*__________

AT SUPERIOR PEDICLE--

4. LATERAL RECESS *L4* right____________________left_________

L5 right____________________left_________

S1 right____________________left_________

5. INTERFACET *L4*____________________________*L5*__________

*S1*________

CANAL SHAPE:

1. Oval *L4*__________________________________*L5*__________
2. Triangular *L4*____________________________*L5*__________
3. Deltoid *L4*_______________________________*L5*__________
4. Trefoil *L4*_______________________________*L5*__________

ADDITIONAL COMMENTS____

APPENDIX F

Postoperative Routine

APPENDIX F

Postdiscectomy Pool Program for Dr. Greenhill, Dr. Petruk & S. Kushner's Discectomy Study

Day of surgery - bed rest
Day 1 - Initial standing at bedside
- Assisted ambulation on ward

Day 2 - Assisted ambulation on ward
- May sit 5-10 minutes at a time
- Pool Therapy per stretcher--floated off
- Instructed in posture, extension exercises, ambulation in pool

Day 3 - Pool per stretcher, sit and walk in
- Commence sitting as above if not already

Day 4 - Pool per wheelchair or walking
- Up ad lib on ward

Day 5+ - As above.

Discharge is usually on the fifth to seventh post-op day. There is no pool therapy on the weekend.

Postoperative Pool Program for Postdiscectomy Patients

Back Exercises:

1. Standing facing wall bar - push back from bar and allow hips to sag slowly toward wall. Hold for one second and then release. Repeat five times.
2. Standing facing wall bar - slowly move one leg straight back tightening buttocks and keeping shoulders erect. Hold for one second, then relax. Repeat five times.
3. Standing with back to wall - posture correction by tightening buttocks, doing a pelvic tilt (ie. tighten abdominal muscles so that you feel an increase in muscle tone, but no actual back movement) and pulling shoulder blades down and back. Hold for five seconds, and take slow deep breaths. Repeat five times.
4. Walking in pool, forward and backward, emphasizing erect trunk.
5. Prone in water hanging onto wall bar - flutter kick. Three sets of five repititions.
6. Prone in water - maintain float with hands forward on stairs or seat under water. Add this exercise when all the above are comfortable, as this helps to increase back extension. Repeat five times.

Instructions: Spend majority of time standing, walking or lying; sitting for short periods only with buttocks well to back of chair. Ensure correct posture in all positions. General activity recommended is swimming.

APPENDIX G

Raw Data Table

APPENDIX G

Raw Data Table

```
 3 JUN 85    SPINAL CANAL MEASUREMENTS IN LUMBAR DISCECTOMY PATIENTS
21:50:07     University of Alberta

                            P P P P       S S
                    C     T A A A A  S  S L L  W  W                      F    F
                    R T   R I I I I  L  L R R  L  L                      L    L     E    E
      L       T     O R   E N N N N  R  R P P  R  R                      E    E     X    X
    S E       R     S I D F B W B W  D  D M M  D  D                      X    X     T    T
    U V S  S  A     S A E O B B A A  B  A B A  B  A                      B    A     B    A                                     A
    R E E  A  N     E N L I E E F F  E  F E F  E  F                      E    F     E    F                                     G
 ID G L X  G  S     C G T L F F T T  F  T F T  F  T WLRPMBEF WLRPMAFT    F    T     F    T RFLEXBEF RFLEXAFT LFLEXBEF LFLEXAFT  E

  1 G 5 M 18 28  3.60 0 1 0 1 5 0 3 15 65 1 0 35 65     1        0      1.0  4.5  2.00 4.25    3.0      5.5      5.0      8.0  33
  2 G 4 M 17 27  3.40 0 1 0 1 5 0 5 15 20 1 1 35 40     1        1      1.5  1.0  7.00 5.75    7.0      4.0      8.0      6.5  46
  3 G 5 M 16 36  3.42 0 0 1 0 5 0 1 65 80 1 0 85 83     1        0      3.0  5.0  4.25 3.00    4.0      7.0      4.5      7.0  29
  4 P 5 M 15 29  3.00 0 0 1 2 2 1 2 35 50 1 1 80 65     0        0      3.5  2.5  3.75 4.25    6.0      6.0      6.5      7.5  27
  5 G 5 M 16 28  2.72 0 1 0 1 4 0 1 15 75 1 0 45 85     1        0      2.5  5.0  4.75 5.00    9.0      7.0     10.0      7.0  28
  6 G 5 F 14 32  3.01 0 0 1 2 5 0 2 25 65 1 0 60 70     1        0      2.0  5.0  5.50 3.00    5.0      4.0      9.0      7.0  24
  7 G 4 M 23 27  4.38 1 0 0 1 4 1 2 36 55 1 0 45 70     1        0      4.5  5.0  4.00 2.75    4.5      3.0      6.0      4.0  53
  8 P 4 M 19 24  3.21 1 0 0 1 5 0 1 20 60 1 0 25 70     1        0       .0  6.0   .00 2.25    6.0      4.5      1.0      4.0  32
  9 G 5 F 18 29  3.51 1 0 0 2 5 0 1 30 90 1 0 60 75     0        0      2.0  4.0  2.25 3.50    2.0      3.5      2.0      3.5  56
 10 G 5 M 15 33  3.23 0 0 1 2 5 0 2 10 60 1 0 25 60     1        0      1.0  3.5  2.25 3.00    4.0      6.0      5.0      6.0  34
 11 P 4 F 18 23  2.96 1 0 0 2 4 0 1 30 70 1 0 65 70     1        0      5.0  5.0  4.50 2.00    3.0      5.0      2.0      5.0  33
 12 G 4 M 18 28  3.43 1 0 0 0 5 1 4 10 40 1 1 30 30     1        0      2.0  2.0  1.75 2.00    2.0      2.0      2.0      5.0  26
 13 G 4 F 18 24  3.11 1 0 0 2 5 0 2 65 70 1 0 80 75     1        1      1.0  3.0  1.00 2.25    2.0      3.0      5.0      4.0  40
 14 P 5 M 17 27  3.07 1 0 0 2 4 1 3 30 55 1 0 60 60     1        0      5.5  3.0  3.25 2.75    6.0      5.0      7.0      5.0  35
 15 P 4 M 18 28  3.63 1 0 0 2 5 0 2 15 55 1 0 45 60     1        0      1.0  4.0  2.50 2.00    3.0      2.5      3.0      2.5  40
 16 G 5 M 14 29  3.06 1 0 0 2 5 2 3 10 40 1 0 40 45     1        0      2.5  5.0  2.00 2.50    4.0      4.0      5.0      5.5  26
 17 G 5 F 15 29  3.17 0 1 0 2 5 0 1 45 55 1 0 70 65     1        0      2.0  2.5  3.00 3.25    5.0      4.0      3.0      4.5  37
 18 G 5 M 17 34  4.35 0 1 0 1 5 0 2 35 55 1 0 55 60     0        0      4.0  5.0  2.00 3.00    7.0      7.0      6.5      6.0  46
 19 P 5 M 13 30  2.92 0 1 0 2 5 2 5 60 50 0 1 60 60     0        0      6.5  6.5  2.00 2.50    3.5      3.5      4.0      5.0  51
 20 G 5 M 20 40  5.34 0 0 1 2 5 1 2 10 45 1 1 45 60     1        0       .0  5.5   .00 3.00     .0      5.0       .0      6.0  30

NUMBER OF CASES READ =       20    NUMBER OF CASES LISTED =       20
```

APPENDIX H

Correlation of Reliability
and
Percent Error

APPENDIX H

Correlation of Reliability

A Pearson product moment correlation coefficient was used in order to compare the author's CT measurements of the spinal canal to those of Dr. Margaret Sin, a radiologist. The equation which was used was the square root of the following:

$$r = \frac{[N \Sigma XY - (\Sigma X)(\Sigma Y)]^2}{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}$$

(Weber and Lamb 1970)

The three measurements which were analyzed on 15 patients at the L4 level were the sagittal canal diameter, the transverse canal diameter, and the cross-sectional area.

The r is the Pearson product moment correlation coefficient value which was obtained, and the p is the significance level of the correlation value.

	SAGITTAL(cm)		TRANSVERSE(cm)		AREA(cm^2)	
Subject	X(SK)	Y(MS)	X(SK)	Y(MS)	X(SK)	Y(MS)
01	1.8	1.7	2.8	2.9	3.60	3.58
02	1.7	1.7	2.7	2.7	3.40	3.36
03	1.6	1.5	3.6	3.5	3.42	3.42
04	1.5	1.5	2.9	2.9	3.00	3.05
05	1.6	1.6	2.8	2.8	2.72	2.71
06	1.4	1.4	3.2	3.2	3.01	3.03
07	2.3	2.3	2.7	2.8	4.38	4.31
08	1.9	1.8	2.4	2.5	3.21	3.24
09	1.8	1.9	2.9	2.9	3.51	3.53
10	1.5	1.4	3.3	3.3	3.23	3.16
11	1.8	1.8	2.3	2.3	2.96	3.00
12	1.8	1.7	2.8	2.8	3.43	3.42
13	1.8	1.8	2.4	2.4	3.11	3.13
14	1.7	1.7	2.7	2.7	3.07	3.08
15	1.8	1.8	2.8	2.8	3.63	3.58
	r=.9648		r=.9907		r=.9968	
	$p \leq .000$		$p \leq .000$		$p \leq .000$	

Percent Error

The percent error was calculated for the three spinal canal measurements of one patient at L4, and as well for the SLR, WLR, and spinal ROM including forward flexion, extension, right side flexion and left side flexion. Ten repititions of the same measurement were made.

The formula which was used calculated the average deviation (A.D.). This was described as:

$$\text{AVERAGE DEVIATION} = \frac{\Sigma \text{ absolute values of } d}{N}$$

where d=the distance a given score lies from the mean
The percent error was then calculated using the following formula:

$$\% \text{ ERROR} = \frac{100 \times (\text{A.D.})}{\text{MEAN}}$$

(Weber and Lamb 1970)

REP	TRANS	SAG	AREA	SLR	FLEX	EXT	RFLEX	LFLEX
01	2.3	1.5	2.47	80	7.50	3.00	5.5	7.0
02	2.2	1.5	2.51	80	7.50	3.00	6.5	7.0
03	2.3	1.5	2.50	80	7.50	3.25	7.0	7.0
04	2.3	1.5	2.47	80	7.50	3.00	6.5	7.5
05	2.3	1.4	2.48	75	7.00	3.25	6.0	7.0
06	2.3	1.4	2.50	75	7.25	3.50	7.0	7.0
07	2.2	1.5	2.52	75	8.00	3.00	6.5	7.5
08	2.3	1.5	2.50	80	8.00	3.25	7.0	7.0
09	2.3	1.5	2.47	80	8.00	3.25	6.5	6.5
10	2.3	1.5	2.50	75	7.00	3.50	7.0	6.5
AD=	0.032	0.032	0.002	0.23	0.03	0.16	0.04	0.20
MEAN=	2.28	1.48	2.50	78.50	7.53	3.20	6.55	7.00
%ERR=	1.40	2.16	0.63	2.93	3.79	5.00	5.50	2.86

All values of canal measurements were below three percent, so are considered to have acceptable accuracy for research for measurement - where the value being measured remains constant (Weber and Lamb 1970). Range of motion values had slightly larger variability. The majority of this variation was likely attributable to the patient's response

(ROM increasing as testing of the same measure was repeated), therefore the percent error is not a reflection of the investigator's inaccuracy.

APPENDIX I

Curriculum Vita

APPENDIX J

VITA

NAME: Shirley Faye Kushner

PLACE OF BIRTH: Edmonton, Alberta

YEAR OF BIRTH: 1952

POST-SECONDARY EDUCATION AND DEGREES:

Kibbutz Ein Dor, Kibbutz Ein Hashofet
Israel
1970-1971 Hebrew Ulpan

Wingate Institute
Netanya, Israel
1971-1974 Israeli Physical Education Teaching Diploma

University of Alberta
Edmonton, Alberta
1974-1975 B.P.E.

University of Alberta
Edmonton, Alberta
1975-1979 B.Sc.P.T.

HONOURS AND AWARDS:

Province of Alberta Undergraduate Scholarship
University of Alberta,
1975-1978

B.Sc.P.T., First Class Standing, With Distinction
University of Alberta,
1979

U of A Hospital Ladies Auxiliary Education Scholarship
University of Alberta
1982

Canadian Physiotherapy Association Constance Beattie Award
University of Alberta
1983

Canadian Physiotherapy Association Research Scholarship
University of Alberta
1983

Province of Alberta Graduate Scholarship
University of Alberta
1983-1984

Province of Alberta Graduate Scholarship
University of Alberta
1984-1985

RELATED WORK EXPERIENCE:

Teaching Assistant (Anatomy)
University of Alberta
1982-1983

Teaching Assistant (Orthopedics)
University of Alberta
1983

Research Assistant (Electrotherapy)
University of Alberta
1983-1984

PUBLICATIONS:

1. "Tennis Elbow", Physiotherapy Canada, Vol. 31, Number 5, pp. 251-256 (with J. Lehman, M.Sc.)
2. "Medial Tarsal Tunnel Syndrome: A Review", Journal of Orthopedics and Sports Physical Therapy, Vol. 6, Number 1, pp. 39-45, 1984 (with D.C. Reid, M.D.)
3. "Manipulation in the Treatment of Tennis Elbow", Journal of Orthopedic and Sports Physical Therapy, (with D.C. Reid, M.D., in press)